The Guide provides extensive information on topics ranging from the physical basics of lighting through to possible solutions for specific lighting situations – in short, a veritable encyclopaedia of architectural lighting. The knowledge modules make use of the interactive possibilities offered by the Internet, e.g. for illustrating time-dependent phenomena, experiments or contrasts between alternative solutions: www.erco.com/guide
It is inadequate simply to portray the eye as an optical system when describing human perception. It also needs to be explained how the image is interpreted. Both the perceptual psychology and the objects of perception are important factors in understanding lighting design.
Right up until the 18th century people only had two light sources at their disposal: natural daylight and the flame – the latter being the only artificial light source since the Stone Age. These two types of lighting dictated the patterns of life and architecture down through the ages, but a new epoch was ushered in with the invention of gas lighting and then electric lighting.
With the advent of electrical lighting, obtaining illuminance levels similar to those of daylight became a question of how much technical effort one was prepared to invest. At the end of the 19th century, one attempt at providing street lighting was to mount floodlights on lighting towers. However, the glare and harsh shadow produced caused more disadvantages than advantages and so this form of outdoor lighting was soon abandoned. Whereas inadequate light sources were the main problem initially, a prime concern later on was how to sensibly deal with the overabundance of light. Increasing industrialisation gave rise to intensive studies in the field of workplace lighting, investigating the influence of illuminance levels and lighting type on production efficiency. The studies resulted in extensive rules and regulations governing the minimum illuminance levels, the qualities of colour rendition and glare limitation. This catalogue of standards was to serve as a guideline for lighting far beyond the area of the workplace; in fact, it still determines the practice of lighting design right up to the present day. However, this approach left the psychology of perception totally unconsidered. The issues of how people perceive structures clearly and how lighting also conveys an aesthetic effect were beyond the scope of the quantitative lighting rules and regulations.
Restricting the view of human perception to a physiologically orientated level led to unsatisfactory lighting concepts. Approaches at a new lighting philosophy that no longer solely considered quantitative aspects arose in the USA after World War II. Expanding the physiology of the visual apparatus by adding the psychology of perception meant that all factors involved in the interaction between the perceiving observer, the object viewed and the facilitating medium of light now came under consideration. The perception-orientated lighting design no longer primarily thought in the quantitative terms of illuminance levels or luminance distribution, but in terms of the qualitative factors.
The perception-orientated lighting design of the 1960s no longer considered man and his needs as a mere recipient of his visual surroundings but as an active factor in the perception process. The designers analysed what was the significance of the individual areas and functions. Using the pattern of meaning thus established, it was then possible to plan the lighting as a third factor and to develop an appropriate lighting design. This required qualitative criteria and a corresponding vocabulary, which in turn allowed both the requirements placed on a lighting system and the functions of the light to be described.
Introduction

Richard Kelly (1910-1977) was a pioneer of qualitative lighting design who borrowed existing ideas from perception psychology and theatrical lighting and combined them into a uniform concept. Kelly broke away from the rigid constraints of using uniform illuminance as the central criterium of the lighting design. He replaced the question of lighting quantity with the question of individual qualities of light. These were designed according to a series of lighting functions, which were in turn geared towards the perceiving observer. In the 1950s Kelly made a distinction here between three basic functions: ambient luminescence, focal glow and play of brilliants.
**Ambient luminescence**
Kelly called the first and foundational form of light "ambient luminescence". This is the element of light that provides general illumination of the surroundings; it ensures that the surrounding space, its objects and the people there are visible. This form of lighting facilitates general orientation and activity. Its universal and uniform orientation means that it largely follows along the same lines as quantitative lighting design, except that ambient luminescence is not the final objective but just the foundation for a more comprehensive lighting design. The aim is not to produce blanket illumination, or "one size fits all" lighting at the supposed optimum illuminance level, but to have differentiated lighting that builds on the base layer of the ambient light.

**Focal glow**
To arrive at a differentiation, Kelly came up with a second form of light, which he referred to as "focal glow". This is where light is first given the express task of actively helping to convey information. The fact that brightly lit areas automatically draw our attention now comes into consideration. By using a suitable brightness distribution it is possible to order the wealth of information contained in an environment. Areas containing essential information can be emphasised by accented lighting, whereas secondary or distracting information can be toned down by applying a lower lighting level. This facilitates a fast and accurate flow of information, whereby the visual environment is easily recognised in terms of its structures and the significance of the objects it contains. This applies just as equally to orientation within the space (e.g. the ability to distinguish quickly between a main entrance and a side door) as for emphasising certain objects, such as when presenting goods for sale or when highlighting the most valuable sculpture in a collection.

**Play of brilliants**
The third form of light, "play of brilliants", results from the insight that light not only draws our attention to information, but can also represent information in and of itself. This applies above all to the specular effects that point light sources can produce on reflective or refractive materials. Furthermore, the light source itself can also be considered to be brilliant. This "play of brilliants" can add life and ambiance, especially to prestigious venues. What was traditionally produced by chandeliers and candlelight can now be achieved in a modern lighting design by the targeted use of light sculptures or by creating brilliant effects on illuminated materials.
**Glass House**

Architect: Philip Johnson  

It was on this Glass House project that Kelly developed the basic principles of indoor and outdoor lighting which he was to later apply to countless residential and business properties. Kelly avoided the use of blinds for the sunlight because he found they obscured the view and impaired the feeling of distant space. Instead, to reduce the harsh daytime brightness contrast between inside and outside, Kelly used dimmed lighting on the interior walls. For the night, he designed a concept that works with the reflection of the glass facade and retains the spatial feeling. Kelly recommended candles for the interior as this would give sparkle and add an exciting atmosphere. Several lighting components in the outdoor area augment the view out of the living area and create spatial depth. Projectors on the roof illuminate the front lawn and the trees beside the house. Additional projectors highlight the trees in the middle ground and the background, thereby making the landscape backdrop visible.

Photos courtesy of the Kelly Collection.

**Seagram Building**

Architects: Ludwig Mies van der Rohe and Philip Johnson  
Location: New York, New York, 1957

The vision behind the Seagram Building was to have a tower of light that would be recognisable from afar. Working together with Mies van der Rohe and Philip Johnson, Kelly achieved this aim by having the building shine from the inside out. This was done using luminous ceilings in the office levels, whereby a two-stage light switch for the fluorescent lamps enabled energy to be saved at night. The illumined area at the plinth of the building gave the impression that this multi-storey building is floating above the street. An impressive view into the building at night is afforded thanks to uniform vertical illumination of the building's core, produced by recessed ceiling luminaires. A carpet of light starts in the indoor area and continues onto the forecourt. To achieve a uniform pattern of solar protection on the facade during the daytime, the blinds on the windows only have three settings: open, closed and half-open.
New York State Theater
Lincoln Center for the Performing Arts
Architect: Philip Johnson
Location: New York, New York, 1965

For the New York State Theater Kelly explored the use of crystal-line structures for the design of the chandelier in the auditorium and the lighting of the balcony balustrades in the foyer. The chandelier in the auditorium had a diameter of about three meters and consisted of a number of smaller “diamonds of light”. In the foyer, the luminaires on the balustrade were designed to look like jewels in a crown, thereby underlining the grandeur of the room. The light sources were shielded towards the front side of the balustrades, but on the inside their multi-faceted structure produced impressive reflections. This results in brilliance effects comparable with the sparkle of precious stones. In addition, Kelly also conceived the lighting in all the other areas of the Lincoln Center, except the interior of the Metropolitan Opera House.

Kimbell Art Museum
Architect: Louis I. Kahn
Location: Fort Worth, Texas, 1972

The clever use of natural light in the Kimbell Art Museum originates from the teamwork of Louis Kahn and Richard Kelly. Kahn designed a series of North-South orientated galleries whose vaulted ceilings featured a skylight running along their apexes, while Kelly was responsible for the daylight reflector system made of curved aluminium plate. Perforations allow daylight to penetrate through this plate, thereby reducing the contrast between the underside of this reflector and the daylight-illuminated concrete vaulting. The central section of this dished aluminium is kept free of perforations so that direct daylight is shut out. In areas with no UV protection requirements, such as the entrance or the restaurant, a completely perforated reflector is used. Computer programs were used to calculate the reflector contour and the lighting properties that were to be expected. The underside of the daylight reflector system was fitted with tracks and spotlights. Kelly suggested putting plants in the inner courtyards in order to tone down the harsh daylight for the indoor areas.
Yale Center For British Art

Architect: Louis I. Kahn

Louis Kahn teamed up with Kelly to design a system of skylights for the illumination in the Yale Center for British Art. The design brief from the museum was that on sunny and overcast days the pictures were to be exclusively illuminated by daylight. Artificial lighting was only to be mixed in when there was very low daylight. The domed skylights feature a permanently mounted louvre construction on the topside, allowing diffuse northern light into the building while avoiding directly incident light on walls or floors when the sun is high. The skylights are made of an upper Plexiglas dome with UV-protection and a sandwich construction consisting of: a translucent plastic plate for dust protection, a mirror-finish light diffuser and a bi-laminar, acrylic, prismatic lens underneath. Tracks on the undersides of the domed skylights hold wallwashers and spotlights. The design process utilised computer calculations and full-scale models.
In the 1970s, William M. C. Lam (1924-), one of the most committed advocates of qualitatively orientated lighting design, produced a list of criteria, or rather a systematic, context-orientated vocabulary for describing the requirements placed on a lighting system. Lam distinguished between two main groups of criteria: the "activity needs", which are the needs resulting from performing activities within a visual environment, and the "biological needs", which sum up the psychological demands placed on a visual environment and are applicable in every context.
Activity needs
The "activity needs" describe the needs resulting from performing activities within a visual environment. The characteristics of the visual task at hand are the crucial factor for these needs. The analysis of the activity needs is therefore largely identical with the criteria for quantitative lighting. There is also considerable agreement for this area when it comes to the objectives of lighting design. The aim is to arrive at a functional lighting that will provide the optimum visual conditions for the activity in question – be it work, leisure activities or simply moving through the space. In contrast to the proponents of quantitative lighting design, Lam objects to a uniform lighting that is simply designed to suit whatever is the most difficult visual task. Instead, he proposes a differentiated analysis of all the visual tasks that arise, an analysis conducted according to location, type and frequency.

Biological needs
Lam sees the second complex of his system, i.e. the "biological needs", as being more essential. The biological needs sum up the psychological demands that are placed on a visual environment and are applicable in every context. Whereas activity needs result from a conscious involvement with the surroundings and are aimed at the functionality of a visual environment, biological needs largely concern unconscious requirements which are fundamental for evaluating a situation emotionally. They are concerned with the feeling of wellbeing in a visual environment. The starting point for Lam's definition is the fact that our attention is only dedicated to one specific visual task in moments of utmost concentration. Our visual attention almost always widens to observe our entire surroundings. This allows changes in the environment to be perceived immediately and behaviour to be adapted to the altered situation without delay. The emotional evaluation of a visual environment depends not least on whether that environment clearly presents the required information or whether it conceals it from the observer.

Orientation
Of all the fundamental psychological demands placed on a visual environment, Lam ranks the need for clear orientation as paramount. Orientation can be initially understood in spatial terms here. In which case, it would then relate to how discernable destinations and routes are and to the spatial location of entrances, exits and other specific facilities within the environment, e.g. a reception desk or the individual areas of a department store. But orientation also concerns information on further aspects of the surroundings, such as the time of day, the weather or what is going on in that area. If this information is missing, as may be the case in closed spaces in department stores or in the corridors of large buildings, then the environment is perceived as unnatural and even oppressive. It is only by leaving the building that we can catch up with the information deficit.
Discernability
A second group of psychological needs concerns how well the surrounding structures can be discerned and comprehended. The first point to note here is that all areas of the spaces are sufficiently visible. This is the decisive factor for our feeling of security within a visual environment. Dark corners in subways or in the corridors of large buildings may harbour danger, in the same way as glaringly overlit areas. Comprehension of our surroundings does not simply mean that absolutely everything has to be visible however, it also includes an element of structuring, i.e. the need for a clearly structured and ordered environment. We perceive situations as positive not only when the form and structure of the surrounding architecture are clearly discernable, but also when the essential areas are clearly delineated from their background.

Communication
A third area covers the balance between man’s need for communication and his requirement for a defined private sphere. Both extremes here are perceived as negative, i.e. complete isolation as well as “life in a goldfish bowl”. A given space should facilitate contact with other people, yet at the same time it should also allow private areas to be defined. One such private area could be defined by a patch of light that picks out a group of seats or a conference table from the overall surroundings within a larger room.
The majority of the information that we receive about the world around us comes through our eyes. Light is not only an essential prerequisite, it is the medium by which we are able to see. Through its intensity, the way it is distributed and through its properties, light creates specific conditions which can influence our perception. Lighting design is, in fact, the planning of our visual environment. Good lighting design aims to create perceptual conditions which allow us to work effectively and orient ourselves safely while promoting a feeling of well-being in a particular environment. At the same time it enhances the environment in an aesthetic sense. The physical qualities of a lighting situation can be calculated and measured. Ultimately, it is the actual effect the lighting has on the user of a space and his subjective perception, that decides whether a lighting concept is successful or not.
When describing human perception, it is inadequate to portray the eye as an optical system. The process of perception is not a matter of how an image of our environment is transferred to the retina, but how the image is interpreted and how we differentiate between objects with constant properties in a changing environment.
Eye and camera

The process of perception is frequently explained by comparing the eye with a camera. In the case of the camera, an adjustable system of lenses projects the reversed image of an object onto a film. The amount of light is controlled by a diaphragm. After developing the film and reversing the image during the enlarging process, a visible, two-dimensional image of the object becomes apparent. Similarly, in the eye, a reversed image is projected onto the retina of the eye via a deformable lens. The iris takes on the function of the diaphragm, the light-sensitive retina the role of the film. The image is then transported via the optic nerve from the retina to the brain, where it is adapted in the visual cortex and made available to the conscious mind.

In regard to the eye, however, there are considerable differences between what is actually perceived and the image on the retina. The image is spatially distorted through its projection onto the curved surface of the retina. Through chromatic aberration – light of various wavelengths is refracted to varying degrees, which produces coloured rings around the objects viewed. These defects, however, are eliminated when the image is being processed in the brain.

Perspective

If we perceive objects that are arranged within a space, the perspectives of the images produced on the retina are distorted. A square perceived at an angle, for example, will produce a trapezoidal image on the retina. This image may, however, also have been produced by a trapezoidal surface viewed front on. The only thing that is perceived is one single shape – the square that this image has actually produced. This perception of a square shape remains consistent, even if the viewer or object move, although the shape of the image projected on the retina is constantly changing due to the changing perspective.

Chromatic aberration. Images are blurred due to the various degrees of refraction of spectral colours.

Spherical aberration. Projected images are distorted due to the curvature of the retina.

Perceptual constancy: perception of a shape in spite of the fact that the image on the retina is changing with the changing perspective.
Guide

Basics | Seeing and perception | Physiology of the eye

Receptors

There are two different types of receptor: the rods and the cones, which are not distributed evenly over the retina. At one point, the so-called “blind spot”, there are no receptors at all, as this is the point at which optic nerves enter the retina.

Receptor density

An area of the retina called the fovea is the focal point of the lens. In this area, the concentration of the cones is greatest, whereas the density of the cones reduces rapidly outwards to the periphery. Here we find the greatest concentration of rods, which do not exist in the fovea.

Rods

The older of these two systems, from an evolutionary point of view, is the one consisting of rods. The special attributes of this system include high light-sensitivity and a great capacity for perceiving movement over the entire field of vision. On the other hand, rods do not allow us to perceive colour; contours are not sharp and it is not possible to concentrate on objects, i.e. to study items clearly even if they are in the centre of our field of vision. The rod system is extremely sensitive and is activated when the illuminance level is less than 1 lux. Our night vision features, particularly the fact that colour is not evident, contours are blurred and poorly lit items in our peripheral field of vision are more visible – can be explained by the properties of the rod system.

Cones

The cones form a system with very different properties. This is a system which we require to see things under higher luminous intensities, i.e. under daylight or electric light. The cone system has lower light-sensitivity and is concentrated in the central area in and around the fovea. It allows us to see colours and sharper contours of the objects on which we focus, i.e. whose image falls in the fovea area. In contrast to rod vision, we do not perceive the entire field of vision uniformly; the main area of perception is in the central area. The peripheral field of vision is also significant, if interesting phenomena are perceived in that area; in that case our attention is automatically drawn to these points. This is then received as an image on the fovea to be examined more closely. Apart from noticing sudden movement, striking colours and patterns, the main reason for us to change our direction of view is the presence of high luminances – our eyes and attention are attracted by bright light.
One of the most remarkable properties of the eye is its ability to adapt to different lighting conditions. We can perceive the world around us by moonlight or sunlight, although there is a difference of a factor of 100,000 in the illuminance. The extent of tasks the eye is capable of performing is extremely wide – a faintly glowing star in the night sky can be perceived, although it only produces an illuminance of 10–12 lux on the eye.

Typical illuminances \( E \) and luminances \( L \) under daylight and electric lighting.

### Luminance

Luminance range \( L \) of rod vision (1), mesopic vision (2) and cone vision (3). Luminances (4) and preferred luminances (5) in interior spaces. Absolute threshold of vision (6) and threshold of absolute glare (7).

Adapting from dark to light situations occurs relatively rapidly, whereas adapting from light to darkness requires a considerably longer time. A good example of this is how bright we find it outside having come out of a dark cinema auditorium during the daytime or the transitory period of night blindness we experience when entering a very dark room. Both the fact that contrast in luminance can only be accommodated by the eye within a certain range and the fact that it takes time to adapt to a new level of lighting, or brightness, have an impact on lighting design. For that reason lighting design requires, for instance, the purposeful planning of different luminance levels within a space or deciding on the adaptation of lighting levels in adjacent spaces.
To understand what visual perception is all about, it is not so much the transport of visual information that is of significance. It is rather the process involved in the interpretation of this information, the creation of visual impressions. The question that arises is whether our ability to perceive the world around us is innate or the result of a learning process. Another point to be considered is whether sensory impressions from outside alone are responsible for the perceived image or whether the brain translates these stimuli into a perceivable image through the application of its own principles of order. There is no clear answer to this question. Perceptual psychology is divided on this point.
Contour

Experience, and the expectations linked with it, may be so strong that missing elements of a shape are perceived as complete or individual details amended to enable the object to meet our expectations. The perception of a shape with missing contours is simply based on shadow formation.

Overall shape

Experience leads us to recognise an overall shape by being able to identify essential details.

Colour

This picture illustrates how a colour is matched to the respective pattern perceived. The colour of the central grey point adjusts itself to the black or white colour in the perceived pattern.
Fixed objects produce retinal images of varying shapes, sizes and brightness. Due to changes in lighting, distance or perspective, this indicates that mechanisms must exist to identify these objects and their properties and to perceive them as being constant. There is no single, simple explanation for the way perception works. Optical illusions provide an opportunity to examine the performance and objectives of perception.
**Brightness**

The perception of brightness of the grey field depends on the environment – in bright surroundings, an identical grey appears darker than in dark surroundings.

The fact that a medium grey area will appear light grey if it is bordered in black, or dark grey if it is bordered in white. This can be explained by the fact that the stimuli perceived are processed directly – brightness is perceived as a result of the lightness contrast between the grey area and the immediate surroundings. What we are considering here is a visual impression that is based exclusively on sensory input which is not influenced by any criteria of order linked with our intellectual processing of this information.

**Luminance gradient**

The continuous luminance gradient across the surface of the wall is interpreted as a property of the lighting. The wall reflectance factor is assumed to be constant. The grey of the sharply framed picture is interpreted as a material property, although the luminance is identical to the luminance in the corner of the room.

**Three-dimensionality**

Changing luminance levels may arise from the spatial form of the illuminated object; examples of this are the formation of typical shadows on objects such as cubes, cylinders or spheres.

The spatial impression is determined by the assumption that light comes from above.

By inverting the picture, the perception of elevation and depth is reversed.

The spatial form of an object can be recognised by the gradient of the shadows.
Irregular or uneven luminances can result in confusing lighting situations. This is evident, for example, when luminous patterns created on the walls bear no relation to the architecture. The observer’s attention is drawn to a luminous pattern that cannot be explained through the properties of the wall, nor as an important feature of the lighting. If luminance patterns are irregular, they should, therefore, always be aligned with the architecture.

Light distribution that is not aligned with the architectural structure of the space is perceived as disturbing patterns that do not relate to the space.

The visible pool of light determines whether it is perceived as background or as a disturbing shape. Light distribution that is not aligned with the shape of the picture is perceived as a disturbing pattern.

The perception of colour, similar to the perception of brightness, is dependent on neighbouring colours and the quality of the lighting. The necessity for us to be able to interpret colours is based on the fact that colour appearances around us are constantly changing. A colour is therefore perceived as being constant both when viewed in the bluish light of an overcast sky or in warmer direct sunlight – colour photographs taken under the same conditions, however, show the distinct colour shifts that we must expect under the particular type of light.
Perspective

Our misinterpretation of lines of the same length shows that the perceived size of an object does not depend on the size of the retina image alone, but that the distance of the observer from the object is significant. Vice versa, objects of known sizes are used to judge distances or to recognise the size of adjacent objects. From daily experience we know that this mechanism is sufficient to allow us to perceive objects and their size reliably. Therefore, a person seen a long way away is not perceived as a dwarf and a house on the horizon not as a small box. Only in extreme situations does our perception deceive us: looking out of an aeroplane, objects on the ground appear to be tiny; the viewing of objects that are considerably farther away, e.g. the moon, is much more difficult for us to handle.

Size

To allow for the perception of size, we have a mechanism that balances the perspective distortion of objects. It guarantees that the changing trapezoidal and ellipsoidal forms in the retina image can be perceived spatially as being normal, rectangular or round objects by being aware of the angle at which the object is viewed.
Before a property can be attributed to an object, the object itself must be recognised, that is to say, distinguished from its surroundings. This process of interpretation has been used to formulate laws according to which certain arrangements are grouped together to form shapes, i.e. objects of perception. These laws of gestalt are of practical interest to the lighting designer. Every lighting installation comprises an arrangement of luminaires – on the ceiling, on the walls or in the space. This arrangement is not perceived in isolation, but in forms or groups in accordance with the laws of gestalt. The architectural surroundings and the lighting effects produced by the luminaires produce further patterns, which influence in our perception of the space.
Closed form

An essential principle of the perception of gestalt is the tendency to interpret closed forms as pure shapes.

Proximity

Elements arranged close together are grouped according to the law of proximity and form a pure shape. The example on the left demonstrates that we first see a circle and then an arrangement of luminaires. The circles are arranged in such a strict order that the imaginary linking lines between them is not straight lines, but forms a continuous circle, not a polygon.

From eight points on, a circle is formed.

Inside

Shapes that are not completely closed can also be perceived as a gestalt. A closed shape is always seen as being on the inside of the linking line – the formative effect therefore only works in one direction. This inner side is usually identical to the concave, surrounding side of the line that encloses the shape. This in turn leads to a formative effect even in the case of arcs or angles, making a pure shape visible inside the line, that is to say, in the partly enclosed area. If this leads to a plausible interpretation of the initial pattern, the effect of the inner side can be significant.

An arc makes a pure shape visible on the inside of the line.
In regard to symmetry, the perception of a form as a pure shape is based on simple, logical structure. On the other hand more complex structures belonging to the same pattern disappear into an apparently continuous background.

When two square luminaires are added to the pattern of circular downlights, the arrangement is perceived according to the law of symmetry to form two groups of five.

A similar result occurs in parallel shapes of equal width. This is not strictly a case of symmetry. A principle of order and organisation is, however, evident, allowing us to perceive a pure shape. Two parallel lines show similarity.

Even without strict symmetry, it is possible to recognise a pure shape.

A basic law of gestalt is to prefer to perceive lines as steady continuous curves or straight lines, and to avoid bends and kinks. Our preference to perceive continuous lines is so great that it can influence our overall interpretation of an image.

Law of gestalt relating to continuous lines. The arrangement is interpreted as two lines crossing.
**Pure form**

The downlight arrangement is grouped into two lines according to the law of pure form. The arrangement is interpreted as two superimposed rectangles.

When it comes to two-dimensional shapes, the law of the continuous line conforms with the law of pure form. In this case, shapes are organised to create figures that are as simple and clearly arranged as possible.

**Identity**

Luminaires of the same type are grouped together.

Besides spatial layout, the structure of the shapes themselves is also responsible for their formation into groups. The shapes in the accompanying drawing are not organised according to proximity or axial symmetry, but in groups of identical shapes. This principle of identity also applies when the shapes in a group are not absolutely identical but only similar.
We are not however, conscious of every object that comes within our field of vision. The way the fovea prefers to focus on small, changing scenes shows that the perception process purposefully selects specific things to look at. This selection is inevitable, as the brain is not capable of processing all the visual information in the field of view. It also makes sense because not all the information that exists in our environment is necessarily relevant to us.
**Activity**

The value of any particular information relates to the current activity of the observer. This activity may be work or movement-related or any other activity for which visual information is required. Lighting conditions under which the visual task can be perceived to an optimum degree can be determined from the above-mentioned specific features. It is possible to define ways of lighting which will be ideal for specific activities.

**Information**

There is another basic need for visual information that goes beyond the specific information required for a particular activity. This is not related to any particular situation; it results from man’s biological need to understand the world especially man’s need to feel safe. To evaluate danger, we must be aware of the structure of the environment. This applies to orientation, weather, time of day and information relating to other activities occurring in the area. If this information is not available, e.g. in large, windowless buildings, the situation is often considered to be unnatural and oppressive.

**Social**

In regard to man’s social needs – the need for contact with other people and the need for private space are somewhat contradictory and require careful balance. The focus on which visual information is required is determined by the activities and basic biological needs. Areas likely to provide significant information – on their own or by being highlighted – are perceived first. They attract our attention. The information content of a given object is responsible for its being selected as an object of perception. Importantly, the information content influences the way in which an object is perceived and evaluated.
Guide
Designing with light

Light plays a central role in the design of a visual environment. The architecture, people and objects are all made visible by the lighting. Light influences our well-being, the aesthetic effect and the mood of a room or area.
It is light that first enables spatial perception. Above and beyond this, our perception of architecture can also be influenced with light: it expands and accentuates rooms, creates links and delineates one area from another.
Forming functional zones
Defining spatial borders
Emphasising architectural features

Light can alter the appearance of a room or area without physically changing it. Light directs our view, influences perception and draws our attention to specific details. Light can be used to divide and interpret rooms in order to emphasise areas or establish continuity between the interior and exterior. Light distribution and illuminance have a decisive influence on how architecture is perceived.
Observation

Light can be used to emphasise individual functional zones in an area, e.g. traffic areas, waiting areas, and exhibition areas. Zonal lighting with delineated beams of light visually separates one area from another. Different illuminance levels establish a perceptual hierarchy and direct the viewer’s gaze. The differentiation of light colours creates contrasts and emphasises individual zones.

Conclusion

Differentiated lighting of functional zones divide up an area and improve orientation. Areas of a space can be separated from each other using narrow beams of light and strong contrasts in brightness. Distinct contrasts between individual zones and their surroundings remove them from their spatial context. Large areas that on the whole are evenly illuminated can appear rather monotone if they are not divided up. Low general lighting provides the basis for adding lighting accents. Lighting control systems allow functional zones to be adapted to different uses.

Applications

Projects:
Private home, New South Wales
Heart of Jesus Church, Munich
Teatri Ravintola, Helsinki
ERCO, Lüdenscheid
Defining spatial borders

Observation

Floor illumination emphasises objects and pedestrian surfaces. Vertical spatial borders are emphasised by illuminating wall surfaces. Uniform light distribution emphasises the wall as a whole, whereas accentuating, grazing light gives the wall structure by adding patterns of light. Bright walls create a high level of diffuse light in the room.

Conclusion

Vertical illumination is used to shape the visual environment. Room surfaces can be differentiated using different levels of illuminance to indicate their importance. Uniform illumination of the surfaces emphasises them as an architectural feature. A decreasing level of brightness across a wall is not as effective as uniform wallwashing at defining room surfaces. Lighting effects using grazing light emphasise the surface textures and become the dominant feature. Indirect lighting of a ceiling creates diffuse light in the room with the lighting effect being influenced by the reflectance and colour of its surface.

Applications

Projects:
Fondación Banco Santander Central Hispano, Madrid
Lamy, Heidelberg
Ezeiza Airport, Buenos Aires
Light and Building, Frankfurt
Emphasising architectural features

Observation

The illumination of architectural details draws attention away from the room as a whole towards individual components. Columns appear as silhouettes in front of an illuminated wall. Narrow-beam downlights emphasise the form of the columns. Grazing light accentuates individual elements or areas and brings out their form and surface texture.

Conclusion

Rooms can be given a visual structure by illuminating the architectural features. By using different levels of illuminance, different parts of a room can be placed in a visual hierarchy. Grazing light can cause highly three-dimensional features to cast strong shadows.

Applications

Projects:
Tokyo International Forum
St. Petri church, Stavanger
Palacio de la Aljaferia, Zaragoza
Catedral de Santa Ana, Las Palmas
Combining rooms can create complex architectural patterns. Light interprets these in terms of their structure and orientation. Targeted lighting enables the viewer to look into an area and creates spatial depth. The consideration of material qualities in combination with the correct illuminance, colour of light and light distribution is an important aspect in the design stage.
Observation

The bright rear wall gives the room depth and accentuates the spatial perspective. Illuminated objects in the background achieve a similar effect. If the emphasis of the illuminance level is shifted from the back to the front area of the room, then the focus of attention will also shift from the background to the foreground.

Conclusion

Light makes surfaces or objects visible and allows them to become the focus of attention. Dark spatial zones cause spatial limits to disappear and recede into the background. Differentiated spatial lighting can produce a hierarchy of how spaces are perceived. Illuminating vertical surfaces is of particular creative importance for the design since a better effect is achieved as the result of spatial perspective than when illuminating horizontal surfaces.

Applications

Projects:
- Museum Georg Schäfer, Schweinfurt
- Catedral de Santa Ana, Las Palmas
- DZ Bank, Berlin
- Guggenheim Museum, Bilbao
A high illuminance level in the interior combined with a dark exterior creates a strong reflection on the facade plane. The interior visually appears to double in size from the exterior due to the reflection. Objects in the outdoor area are not recognisable. As the illuminance level in the interior decreases and the luminance in the exterior increases, the mirror effect is reduced and objects on the exterior become recognisable.

The reflection on the glass becomes less as the luminance in front of the glass decreases and the luminance behind the glass increases. Well shielded luminaires in front of the glass plane cause less reflection. Lower illuminance in the interior allows better perception of the exterior. When directing luminaries on the exterior, direct glare into the indoor area should be avoided.

Projects:
Nagasaki Prefectural Art Museum, Nagasaki
Restaurant Olio e Pane, Metzingen
Private home, New South Wales
ABN AMRO, Sydney
Outside – looking inside

Observation

The high illuminance level of daylight causes a strong reflection on the glass surface. Objects in the indoor area are not perceptible. As the illuminance level in the outdoor area decreases, the reflection becomes less. This allows illuminated objects or surfaces in the indoor area to become visible. The glass is no longer perceptible.

Conclusion

The reflection on the glass becomes less as the luminance in front of the glass decreases and the luminance behind the glass increases. Luminaire in front of the glass that are well shielded and integrated into architecture cause less reflection of themselves. A low illuminance level in the indoor area produces a deep spatial effect at night. The illumination of objects in indoor areas – such as shop windows – requires very high illuminance to make these objects visible during the day due to the high illuminance level outside. Adjusting the indoor lighting to the changing daylight is recommendable. A higher illuminance level during the day and a low level in the evening reduces the contrast.

Applications

Projects:
Lamy, Heidelberg
Bodegas Portia, Gumiel de Izán
"Dat Backhus" bakery, Hamburg
Leonardo Glass Cube, Bad Driburg
Outside – looking outside

**Observation**

A bright rear wall lends depth to the room and helps delineate the room limits. Illuminated objects in the background achieve a similar effect. If the emphasis of the illuminance level is shifted from the back to the front area of the room, then the focus of attention will also shift from the background to the foreground.

**Conclusion**

Light makes surfaces or objects visible and brings them into the foreground. Dark zones of the room make the room limits disappear and the effect of areas recedes into the background. Due to the low illuminance level at night, the required illuminances are less than for indoor lighting.

**Applications**

Projects:
Hong Kong Convention and Exhibition Centre
Grote Markt, Antwerp
Federal Chancellery, Berlin
Private home, Milan
Guide

Designing with light | Architectural lighting

Illuminate objects

Light directs our view and focuses the attention on details. The direction of light, illuminance and the light distribution all determine the effect of an object in its surroundings.

Direction of light  Vary the light distribution  Accentuate objects
Directed light from the front produces a strong modelling ability. Light from above causes the object to cast strong shadows on itself. Light from behind creates a silhouette. The steeper the incident light, the more pronounced the shadow effect.

**Observation**

If the light from the front is also coming slightly from one side, it gains a strong descriptive power. Light that is solely head-on hardly causes any shadow in the direction of vision and the object loses some of its 3-dimensional appearance. Very steep incident light is suitable for objects having a very shallow texture in order to make them more 3-dimensional.

**Conclusion**
Arrangement

The steeper the incident light, the more pronounced the shadow effect. Objects can be illuminated well when the direction of light is between 5° and 45° to the vertical. The optimal direction of light for illuminating objects is at 30°. This avoids strong reflected glare or undesirable shadows on people or objects.

Applications

Highlighting is used for modelling objects in:
- museums
- exhibitions
- salesrooms

Preferred luminaire groups
- spotlights
- floodlights

Projects:
Pinacoteca Vaticana, Rome
Guggenheim Museum, Bilbao
Hermitage, St. Petersburg
Hermitage, St. Petersburg
Observation

Narrow-beam spotlights accentuate the object and make it stand out against the surroundings. The beam of light is stretched into an oval using a sculpture lens. Flood lenses spread out the narrow beam and create a soft brightness gradient.

Conclusion

The narrower the beam of light cast on the object, the stronger the effect. Sculpture lenses are particularly suitable for projecting light at objects over their entire height. With their wide light beam, flood lenses illuminate the surroundings stronger and represent the object in its spatial relationship.

Applications

Highlighting is used for modelling objects in:
- museums
- exhibitions
- salesrooms

Preferred luminaire groups:
- spotlights with accessories

Projects:
Bunkamura Museum of Art, Tokyo
Museo del Prado, Madrid
Vigeland Museum, Norway
Hermitage, St. Petersburg
**Observation**

The objects and the wall are given general lighting by wallwashers. Beams from individual spotlights add emphasis to the objects. A higher brightness contrast increases the level of accentuation.

**Conclusion**

When the brightness contrast of the ambient surroundings to the object is 1:2, a contrast can hardly be noticed. When the ratio is 1:5, a minimum brightness contrast is established between primary and secondary points of interest. A contrast of 1:10 brings out the difference very well. A brightness contrast of 1:100 detaches the object very strongly from its ambient surroundings but an unintentional dissection of the wall can arise.

**Applications**

Highlighting of objects on walls is a practice used in:
- museums
- exhibitions
- trade-fair stands
- salesrooms

Projects:
- Museo Ruiz de Luna Talavera, Spain
- German Architectural Museum, Frankfurt
- Guggenheim Museum, Bilbao
- Museo Picasso, Barcelona
Colour is a significant component of visual perception. It cannot be perceived without daylight or artificial lighting. The combination of lamps and filters allows a multitude of design possibilities for emphasising or altering the lighting effect of rooms and objects with coloured light. The term "colour of light" covers both white and coloured light. Warm white, neutral white and daylight white are derived from the white colour of light. The coloured light covers the entire visible spectrum.
The light colour refers to a colour which is emitted by a light source. The light colour is produced as a result of the emitted spectrum of light. The type of light colour is defined by hue, saturation and brightness. Using filters produces coloured light. This enables the colouration of rooms to be modified without changing the rooms physically. Mixing several light colours is referred to as additive colour mixing.

The body colour arises as a result of the incident light and the specific absorption properties of the surface. Therefore, the tri-stimulus value of a body colour can only be determined in combination with the type of light with which it is illuminated. In addition to hue, brightness and saturation, the body colour of an object is also defined by the reflectance. When illuminating coloured walls or objects with coloured light, the reciprocal effect of light colour and body colour is paramount. This interplay is the basis of subtractive colour mixing. The chromatic effects can be intensified or altered.
In the CIE standard colorimetric system, body colours and light colours are represented in a continuous, two-dimensional diagram. The spectral constitution of light colours results from the type of light, while that of body colours results from the type of light and the spectral reflectance or transmittance. The dimension of brightness is left unconsidered here; this means that only the hue and saturation of all colours can be determined in the diagram. The coloured area is enclosed by a curve on which the chromaticity locations of the completely saturated spectral colours lie. At the centre of the area is the point of least saturation, which is designated as a white or uncoloured point. All levels of saturation of one colour can now be found on the straight lines between the uncoloured point and the chromaticity location in question. Similarly, all mixtures of two colours are likewise to be found on a straight line between the two chromaticity locations in question. Complementary colours are located opposite each other in the CIE model and combine to form white.

In the Munsell system, body colours are arranged according to the criteria of brightness, hue and saturation to produce a complete sample catalogue in the form of a three-dimensional matrix. Brightness here refers to the reflectance of a body colour; the hue refers to the actual colour, while the term saturation expresses the degree of coloration, from the pure colour down to the uncoloured greyscale. Whereas a two-dimensional diagram is sufficient for colours of light, a three-dimensional system is required for body colours due to reflectance.
**Observation**

The higher red component in warm white light allows rooms to appear warmer than with neutral white light. The higher blue component in daylight white light creates a cooler atmosphere.

**Conclusion**

Warm colours of light are preferred above all at lower illuminances and with directed light, whereas cold colours of light are accepted at high illuminances and diffuse illumination. White light is described by specifying the colour temperature, colour rendition, chromaticity location and spectrum. The white colour temperature is divided into three main groups: warm white, neutral white and daylight white. A good colour rendition with the lighting will only produce a low colour deviation. The chromaticity location identifies the colour within the CIE diagram.

**Applications**

On presentation lighting, making specific use of colours of light allows luminous colours to be achieved on the objects being illuminated. Daylight white light is often used in office rooms to augment the daylight.

**Projects:**
- Sony Center, Berlin
- Glass pavilion, Glass technical college, Rheinbach
- Hong Kong and Shanghai Bank
- ERCO, Lüdenscheid
**Observation**

Compared to the primary colours yellow, blue and red, the colours amber and magenta appear weaker in their expressiveness. Yellow and red colours of light create a warm atmosphere in a room. Blue colours of light allow a room to give a cooler impression.

**Conclusion**

In architectural lighting, colours from the daylight spectrum are felt to be natural: magenta (conditions of light at sunset), amber (atmospheric light at sunrise), night blue (clear night sky) and sky blue (light of the sky by day). For coloured light, the data concerning chromaticity location and spectrum are important. The chromaticity location is specified by the co-ordinates in the CIE diagram, whereby a colour of light can be formed by different colour spectra.

**Applications**

Coloured light is used for:
- exhibitions
- trade-fair stands
- salesrooms
- event lighting

**Projects:**
- ERCO P3, Lüdenscheid
- Zürich Insurance, Buenos Aires
- Teattri Ravintola, Helsinki
- Teattri Ravintola, Helsinki
Observation

Super imposing several colours of light is an additive mixing process. Mixing two of the primary colours red, green and blue results in magenta, cyan or yellow. By mixing the three primary colours in equal amounts, white light is produced.

Conclusion

When illuminating objects with differently coloured light sources, the spatial superimposition gives rise to interesting additive colour mixing effects, which may even include coloured shadows.
**Observation**

Subtractive colour mixing occurs when coloured surfaces are illuminated with coloured light. Mixing two of the subtractive primary colours magenta, cyan and yellow, produces the additive primary colours red, green or blue. Warm body colours are emphasised by a warm white colour of light. Cold body colours appear brighter and more saturated under cold neutral colours of white light, especially daylight white.

**Conclusion**

The appearance of a body colour can seem more saturated and brighter when the lighting on it is of similar colour. Body colours appear less saturated, or darker, when the coloured lighting is dissimilar. The actual appearance of the results of subtractive colour mixing depends on the spectral constitution of the components being mixed.

**Applications**

In practice, when illuminating coloured surfaces, it is recommendable to perform lighting tests or calculations. The same applies to the use of colour filters.

**Projects:**
- Indre quay, Haugesund
- Apropos Cöln The Concept Store, Cologne
- Teatini Ravintola, Helsinki
- ERCO Trade Fair, Hanover
The quality of the reproduction of colours is termed colour rendition. Linear spectra have a very good colour rendition. Linear spectra only permit one single colour to be perceived well. Multiline spectra reproduce several colours of the relevant spectrum well, but in the intermediate areas the colour rendition is weaker. Blue and green colours appear comparatively grey and matt under warm white incandescent light despite excellent colour rendition. However, these hues appear clear and bright under daylight white light from fluorescent lamps – despite poorer colour rendition. When rendering yellow and red hues, this phenomenon of respective weakening and intensifying of the chromatic effect is reversed.

**Observation**

**Incandescent lamp**
Continuous spectra lead to good colour rendition. Incandescent lamps or daylight have the colour rendition index Ra 100.

**Daylight**
Continuous spectra lead to good colour rendition. Incandescent lamps or daylight have the colour rendition index Ra 100.
Conclusion

Because the eye is able to adapt to light of the most different colour temperatures, the colour rendition must be determined dependent on the colour temperature. Tungsten halogen lamps feature very good colour rendition. The rendition quality of fluorescent lamps and metal halide lamps ranges from good to average. The degree of colour distortion against a reference light source is indicated using the colour rendition index Ra or the colour rendition grading system. The colour rendition index is only used for white colours of light.

Fluorescent lamp
Discharge lamps such as fluorescent lamps or metal halide lamps feature a multiline spectrum. Their colour rendition is therefore lower than Ra 100.

Physics

The same colours of light can produce a different rendition of a body colour due to different spectral constitution. Continuous spectra lead to a uniform colour rendition. Linear spectra only correctly render a very small colour range. Multiline spectra are compiled from different linear spectra and thus improve the colour rendition. The more spectra can be bound to one linear progression, the better the colour rendition. Incandescent lamps feature a linear spectrum, while discharge lamps have a multiline spectrum.

Applications

Very good colour rendition is important for
- exhibitions
- trade-fair stands
- salesrooms
- offices
- workstations
Observation

- Red is the colour of fire and the expression for power, warmth and energy. The colour has a dominant effect. Where pale red is concerned, the aspect of warmth decreases while its lightness increases.
- Yellow is the lightest colour in the colour wheel, but used in the foreground it does not have the same energy as red.
- Blue is the colour of the sky and is one of the cold colours which gives an effect of depth. Dark navy blue has a rather melancholy effect, whereas blue-green emanates peace.
- Green is the colour of vitality. Its nuances range from calming to refreshing.
- White is one of the non-colours and is the polar opposite of black. White stands for purity.
- Black stands for darkness and appears sinister and negative.
- Grey is one of the non-colours and appears indifferent.

Conclusion

The effect of colours is explained from the physiological point-of-view of actually seeing colour and the psychological aspects of sensory perception. The lure of colours triggers associations and is interpreted in the context of the social and cultural environment. The different hues belonging to a colour can, in turn, also have other effects. The effect of individual colours can be increased by way of a colour contrast.

Applications

- exhibitions
- trade-fair stands
- sales areas
- restaurants

Projects:
Iittala Flagship Store, Amsterdam
Light and Building 2000, Frankfurt
Restaurant Aioli, Vienna
Teatrito Ravintola, Helsinki
**Guide**

Designing with light  |  Architectural lighting  |  Design with coloured light

**Colour contrast**

**Colours themselves**

The seven colour contrasts originated from the colour theory of Johannes Itten. This approach is not based on physical and chemical properties of colours, but on their subjective effects.

The primary colours yellow, red and blue produce the strongest contrast. The colour contrast becomes weaker with secondary or tertiary colours or as the saturation decreases.

**Light-dark**

The "non-colours" black and white produce the strongest contrast. Even with the "proper" colours, their effect is significant. A light colour next to a dark colour has a stronger effect than next to an equally light or lighter colour. The effect of hues can be intensified by greater differences in brightness.

**Cold-warm**

In the colour wheel, the warm colours with red and yellow components are located opposite to the cold blue hues. Green and magenta form the neutral transitions. The effect of a predominant colour can be increased when combined with an accent from the opposite colour.
The effect of the simultaneous contrast has its origin in how the eye processes perception. After staring at a colour for a long time and then looking at a neutral grey, the eye forms a simultaneous contrast colour. Red leads to a green tinged grey shade. Green causes a grey area with a red tinge to appear. Colours change their effect due to the influence of the surrounding colours.

The pairs of colours lying opposite in the colour wheel form the complementary contrast from a primary colour and the secondary (mixed) colour made of the other two primary colours. Yellow-violet displays the largest light-dark contrast, orange-blue the largest cold-warm contrast. Red-green have the same light intensity. The complementary contrast causes the brilliance of the colours to increase.
**Quality**

The quality contrast, or intensity contrast, describes the distinction between pure colours and murky colours. Mixing pure colours with grey shades makes the former murky and dull, and the quality of colour purity is lost. Pure colours have a dominating effect over murky colours.

**Quantity**

The quantity contrast refers to the relationship of the size of one coloured area with the next. A large coloured area with a small area in a contrast colour increases the chromatic effect of the main colour.
Observation

White light that is reflected by a coloured surface takes on the colour of the surface and becomes the predominant colour of light for the whole room. When lighting a coloured wall with coloured light, this effect can be increased, reversed or inverted.

Conclusion

The colour of light in a room is influenced by the decoration of the room. In comparison to diffuse light, direct light increases the effect of the light when illuminating a coloured surface. The effect of a body colour can be intensified by using coloured light of a similar colour. Strong colour contrasts appear brighter for the same illuminance than a weaker colour contrast. Lesser colour contrasts can be perceived better under brighter lighting. Within closed rooms the effect is hardly perceptible due to the phenomenon of colour constancy.

Applications

In practice, when illuminating coloured surfaces, it is recommended that lighting tests or calculations be carried out. Coloured accent lighting is used for:
- exhibitions
- trade-fair stands
- sales areas
**Observation**

Coloured accent lighting and coloured background lighting changes the effect of objects in the room. The colour saturation of the object increases in the foreground when the background brightness is decreased. Blue colours seem to recede into the background, while the chromatic effect makes magenta come to the fore.

- Wall: White  
  Stele: Night blue

- Wall: Magenta  
  Stele: White

- Wall: Amber  
  Stele: Magenta

- Wall: Sky blue  
  Stele: Amber

**Conclusion**

Lighting effects can be intensified using coloured light. Strong colour contrasts increase the brightness contrasts. High brightness contrasts likewise increase the colour contrasts. Natural overall effects arise due to warm colours of light and filter colours such as "Skintone", magenta and amber, or due to cold colours of light such as sky blue and night blue.

**Applications**

- Coloured accent lighting is used for
  - exhibitions
  - trade-fair stands
  - sales areas

**Projects:**
- Museo de Bellas Artes, Bilbao
- Zürich Insurance, Buenos Aires
- Teatri Ravintola, Helsinki
- Light and Building 2002, Frankfurt
The planning process provides an overview of the sequence of the individual tasks in lighting design. This process is closely linked with the planning procedure for an architectural design. The findings of the analysis are firstly channelled into the concept planning and are then finalised for implementation in the design. In addition, maintenance schedules are a prerequisite for maintaining the quality of light on site.
Project analysis

The basis for every lighting design concept is an analysis of the project; the tasks the lighting is expected to fulfil, the conditions and special features. A quantitative design concept can to a large extent follow the standards laid down for a specific task. Standards dictate the illuminance level, the degree of glare limitation, the luminous colour and colour rendering. When it comes to qualitative planning, it is necessary to gain as much information as possible about the environment to be illuminated, how it is used, who will use it and the style of the architecture.

Utilisation of space

A central aspect of project analysis is the question of how the spaces that are to be illuminated are used; it is important to establish what activity or activities take place in the environment, how often and how important they are. This comprehensive analysis of the task gives rise to a series of individual visual tasks, the characteristics of which must in turn also be analysed. Two criteria relating to a visual task are the size and contrast of the details that have to be recorded or handled; there then follows the question of whether colour or surface structure of the visual task are significant, whether movement and spatial arrangement have to be recognized or whether reflected glare is likely to be a problem. The position of the visual task within the space and the predominant direction of view may also become central issues.
Psychological requirements

The psychological requirements include perception of the wider surroundings to establish the time of day, the weather and to facilitate spatial orientation. In large buildings frequented by different users, the need for visual guidance can become an important issue. An orderly and clearly structured environment contributes to the general feeling of wellbeing. Differentiated lighting can provide spatial delineation for areas with separate functions. Where there are conversational zones within larger areas, it may make sense to create private areas by using suitable lighting.

Architecture and ambience

From the point of view of architecture and ambience, a building or space should be made visible, its characteristics accentuated and its ambience underlined. This requires detailed information on the architecture and on the overall architectural concept complete with the intended indoor and outdoor effect by day and night, the use of daylight and the permissible energy consumption. This also includes information on materials, reflectance and the colour scheme. In Architectural lighting it’s not primarily about the lighting which emphasises the building structures and characteristic features for a particular perspective, but rather how to create the required aesthetic effect in a space. The question of the building shape, of spatial shape, modules and rhythmical patterns, which can be identified and expressed by light and luminaires – constitutes the central issue.
Lighting concepts list the properties that lighting should possess. They give no exact information about the choice of lamps or luminaires or about their arrangement. Project analysis provides lighting quality guidelines giving information about the individual forms of lighting. These relate to the quantity and various quality features of light, and also gives the degree of spatial and temporal differentiation. A practical design concept requires consultation with the other trades involved. It must meet the specifications of the relevant standards and take both investment costs and running costs into consideration. The challenge of a qualitative lighting design is to develop a design concept that combines the technical and aesthetic requirements of complex guidelines. A concept that delivers the required performance with a commensurate level of technical expertise and the highest level of artistic clarity will produce the most convincing solution.

In the design phase, decisions are made regarding the lamps and luminaires to be used, the arrangement and installation of the luminaires and any required control gear and control devices. This also allows a reliable calculation of illuminance and costs. No strict process can be set out, nor even one describing generally routine design stages. The decision regarding lamp type can be made at the beginning of a project or left until an advanced planning stage; luminaire arrangement can be determined by the choice of a certain luminaire or could be the criteria for luminaire selection. Lighting design should be seen as a cyclical process in which developed solutions are repeatedly compared to the stated requirements.
A wide range of luminaire types – e.g. spotlights and light structures – are exclusively designed to be installed as additive elements. They may be mounted on track or lighting structures, suspended from the ceiling (pendant luminaires) or surface mounted onto the wall or ceiling. The range of downlights and louvered luminaires available is so vast and their designs differ substantially, which means that numerous modes of installation are required. In the case of wall or floor mounting the luminaires may be surface-mounted or recessed into the fabric of the building. Ceiling mounting allows a variety of possibilities: recessed mounting, surfaced mounting or pendant mounting. The Installation Instructions for the luminaires explain the installation and maintenance of the luminaires in detail.

The maintenance of a lighting installation generally comprises lamp replacement and the cleaning of the luminaires, and possibly also re-adjustment or realignment of spotlights and movable luminaires. The main objective of maintenance is to ensure that the planned illumination is maintained, i.e. to limit the unavoidable reduction of luminous flux of a lighting installation. The reasons for the reduction in luminous flux may be defective lamps and the gradual loss of luminous flux by the lamps or a decrease in light output due to soiling of the reflectors or attachments. In order to avoid a reduction in luminous flux all lamps must be replaced and luminaires cleaned at regular intervals. Qualitative aspects may also be decisive for maintenance. When one lamp in a geometrical arrangement of luminaires fails it may have a detrimental effect on the overall illuminance in the space. The task of the lighting designer is to draw up a maintenance plan that meets the requirements of the given situation and includes the necessary informative literature.
Having completed the project analysis and developed a lighting concept, the next phase entails practical planning: decisions regarding the lamps and luminaires to be used, the arrangement and installation of the luminaires. A detailed design can be developed from a concept based primarily on lighting qualities.
Selecting the right lamp for the luminaire depends on the actual lighting requirements. For the successful implementation of a lighting concept the physical aspects, such as colour rendition, and the functional criteria are decisive.
Modelling

Modelling and brilliance are effects produced by directed light. Compact light sources such as low-voltage halogen lamps or metal halide lamps are a prerequisite for this. When illuminating sculptures, presenting merchandise or lighting interestingly textured surfaces, the modelling ability and brilliance are of central importance.

Colour rendition

The colour rendition of the light source is determined by the actual lamp spectrum. A continuous spectrum ensures the optimal colour rendition. Linear or band spectra generally worsen the colour rendition. A very good colour rendition quality is produced by incandescent lamps including tungsten halogen lamps.

<table>
<thead>
<tr>
<th>LED A QT (12V) TC</th>
<th>HIT</th>
<th>20</th>
<th>40</th>
<th>60</th>
<th>80</th>
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<th>Ra</th>
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Ranges of the colour rendition index Ra for different lamp types

Light colour

The light colour of a lamp depends on the spectral distribution of the emitted light. In practice, the light colours are categorised into warm white, neutral white and daylight white. Warm white lamps emphasise the red and yellow spectral range, whereas blue and green, i.e. cool colours, are accentuated under daylight white light.

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<thead>
<tr>
<th>LED A QT (12V) TC</th>
<th>HIT</th>
<th>2000</th>
<th>3000</th>
<th>4000</th>
<th>5000</th>
<th>6000</th>
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Ranges of colour temperature TF for different lamp types
## Designing with light | Practical planning

### Choice of lamps

#### Luminous flux

<table>
<thead>
<tr>
<th>Lamp Type</th>
<th>1000 lm</th>
<th>8000 lm</th>
<th>6000 lm</th>
<th>4000 lm</th>
<th>2000 lm</th>
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<td>HST</td>
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</table>

Ranges of luminous flux \( \Phi \) for different lamp types

#### Economy

<table>
<thead>
<tr>
<th>Lamp Type</th>
<th>20000 h</th>
<th>10000 h</th>
<th>8000 h</th>
<th>6000 h</th>
<th>4000 h</th>
</tr>
</thead>
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<tr>
<td>LED</td>
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<td>QT (12V)</td>
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<td>HST</td>
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Ranges of service life \( t \) for different lamp types

#### Radiant emission

<table>
<thead>
<tr>
<th>Lamp Type</th>
<th>UV (W/m²)</th>
<th>Light (lm)</th>
<th>IR (W/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A, B, PD</td>
<td>0.05-0.10</td>
<td>6-7</td>
<td>33-40</td>
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<tr>
<td>QT</td>
<td>0.10-0.15</td>
<td>6-6</td>
<td>25-30</td>
</tr>
<tr>
<td>TC</td>
<td>0.20-0.25</td>
<td>2-3</td>
<td>6-30</td>
</tr>
<tr>
<td>HIT</td>
<td>0.20-0.50</td>
<td>2-5</td>
<td>6-30</td>
</tr>
<tr>
<td>HST</td>
<td>0.20-1.00</td>
<td>2-3</td>
<td>6-30</td>
</tr>
</tbody>
</table>

Relative radiated power \( \phi_e \) of different lamp types, with respect to a luminous flux of 1000 lm, subdivided into the wavelength ranges: UV [280 nm–380 nm], visible light [380 nm–780 nm], IR [780 nm–10000 nm].

Example: \( \phi_e = UV \cdot lm / 1000 \)

An A60 lamp with 100W and 1380 lm results in a UV radiated power of 0.069–0.138 W.

Aspects of radiation are important in the field of exhibition and display. Infrared and ultraviolet radiation can cause damage on paintings. High proportions of infrared radiation and convection heat are emitted above all by light sources with low luminous efficacy, such as incandescent lamps or tungsten halogen lamps. With conventional and compact fluorescent lamps the infrared radiation is noticeably lower. The damaging infrared and ultraviolet components can be reduced considerably by using filters.

### Guide

The economy of a lamp depends on the luminous efficacy, the lamp life and the cost of the lamp. Incandescent lamps and tungsten halogen lamps have the lowest luminous efficacies. Clearly larger values are attained by fluorescent lamps, high-pressure mercury vapour lamps and metal halide lamps. Incandescent lamps and tungsten halogen lamps have the lowest lamp life. The life of fluorescent lamps and high-pressure lamps is considerably higher.
The choice of light sources outlines the technical qualities of the lighting design concept and the limits to the lighting qualities that can be achieved. The lighting effects that can be obtained within this range depend on the choice of luminaires in which the lamps are to be used. The choice of lamp and luminaire is therefore closely related. Opting for a particular light source will reduce the choice of luminaire, and vice versa, the choice of luminaire will restrict the choice of lamp.
Uniform general lighting is a standard lighting concept. For general lighting, wide-beam luminaires such as downlights and light structures are suitable. Uniform lighting can also be achieved by indirect illumination. However, a lighting concept that aims solely to create isolated lighting accents is the exception. Often, accent lighting will contain general lighting components to allow the viewer to perceive the spatial arrangement of the illuminated objects. Spill light from the accentuated areas is frequently sufficient to provide adequate ambient lighting. Luminaires that emit a directed, narrow beam can be used for accent lighting. Adjustable spotlights and directional luminaires are ideal.
Direct lighting allows diffuse and oriented light, and both general lighting and accent lighting. A lighting plan can be used with direct lighting that allows differentiated distribution of light. This greatly enhances the three-dimensionality of illuminated objects as the result of high contrasts.

With indirect lighting, lighting is designed to give diffuse general lighting. Indirect lighting produces a highly uniform, soft light and creates an open appearance due to the bright room surfaces. Problems caused by direct and reflected glare are avoided. Indirect lighting alone can give a flat and monotonous environment.
The decision for narrow or wide light distribution is closely connected with the concept of general or differentiated lighting. Luminaires with a beam angle of less than 20° are known as spotlights and above 20° as floodlights. With downlights, the cut-off angle also gives an indication of the width of the light distribution. Wide light distribution creates a higher proportion of vertical illuminance.
Symmetrical light distribution is used for providing even lighting. The light distribution can be wide for downlights used for the general lighting of horizontal surfaces. With spotlights, the light distribution is narrow beamed to provide highlighting. Luminaire with asymmetric light distribution are designed to give uniform light distribution for surfaces located to one side. Typical luminaires with this characteristic are wallwashers and ceiling washlights.

For luminaires with axially symmetrical beam emission, such as light structures, two light intensity distribution curves are given.
Focusing on horizontal lighting is frequently in line with the decision to plan functional, user-orientated light. This applies to the case of lighting for workspaces for instance, where the lighting design is primarily aimed at giving uniform lighting for horizontal visual tasks. In such cases, vertical lighting components are predominantly produced by the diffuse light that is reflected by the illuminated, horizontal surfaces.

The decision to plan vertical lighting may also be related to the task of fulfilling functional requirements when illuminating vertical visual tasks, e.g. for shelves, blackboards or paintings. However, vertical lighting frequently aims to create a visual environment. Vertical lighting is intended to emphasise the characteristic features and dominant elements in the visual environment. This applies not only to the architecture itself, whose structures can be clearly portrayed by illuminating the walls, but also to the accentuation and modelling of the objects in the space.

In most cases the choice of luminaires will be confined to the standard products available, because they can be supplied at reasonably short notice, have clearly defined performance characteristics and have been tested for safety. Standard luminaires can also be used in special constructions, such as lighting installations that are integrated into the architecture (e.g. cove lighting or luminous ceilings). In the case of large-scale, prestigious projects consideration may also be given to developing a custom designed solution or even a new luminaire. This allows the aesthetic arrangement of luminaires in architecture or in a characteristically designed interior and the solution of specific lighting tasks to be effected in closer relation to the project than if only standard products are chosen. Additional costs for development and time considerations must be included in the calculation of overall costs for the project.
The colour of light from a luminaire depends on the lamp. The range of white light colours is divided into warm white, neutral white and daylight white. Coloured light can be produced from these lamps by using colour filters. The use of a coloured light source such as an LED or fluorescent lamp creates coloured light directly and avoids the reduced transmission of colour filters. With luminaires having RGB technology, red, blue and green primary colour light sources can be mixed to give a multitude of colours. An electronic control allows the light colour to be changed dynamically.
There are two basic contrasting concepts for the arrangement of luminaires in an architectural space, which can allocate different aesthetic functions to the lighting installation and provide a range of lighting possibilities. On the one hand, there is the attempt to integrate the luminaires into the architecture as far as possible, and on the other hand, the idea of adding the luminaires to the existing architecture as an element in their own right. These two concepts should not be regarded as two completely separate ideas, however. They are the two extremes at either end of a scale of design and technical possibilities, which also allows mixed concepts and solutions. The decision to opt for a stationary or variable lighting installation overlaps the decision to go for an integral or additive solution; it is determined by the lighting requirements the installation has to meet rather than by design criteria.

In the case of integral lighting, the luminaires are concealed within the architecture. The luminaires are only visible through the pattern of their apertures. Planning focuses on the lighting effects produced by the luminaires. Integral lighting can therefore be easily applied in a variety of environments and makes it possible to co-ordinate luminaires entirely with the design of the space. Integral lighting generally presents a comparatively static solution. The lighting can only be changed by using a lighting control system or by applying adjustable luminaires. Typical luminaires here are recessed wall or ceiling luminaires.
In the case of additive lighting, the luminaires appear as elements in their own right. Besides planning the lighting effects which are to be produced by these luminaires, the lighting designer also has to specify the luminaire design and plan a lighting layout in tune with the architectural design. The range extends from harmonising luminaires with available structural systems to selecting luminaires that will have an active influence on the overall visual appearance. What is gained in flexibility is offset by the task of harmonising the visual appearance of the lighting installation with its surroundings and of avoiding the visual unrest through the mixing of different luminaire types or by a confusing arrangement of light structures. Typical luminaires here are spotlights and light structures, as well as pendant luminaires.

With stationary, mounted luminaires, different light distributions are available, e.g. adjustable luminaires such as directional luminaires. The luminaire layout should be thoroughly checked in the design phase because any subsequent alterations to recessed luminaires are very costly.
There are different ways of making a lighting installation flexible. The highest degree of flexibility, as required for lighting temporary exhibitions and for display lighting, is provided by movable spotlights mounted on track systems or support structures. These allow the luminaires to be realigned, or even rearranged or replaced.
Glare

With regard to glare a distinction is made between direct glare, caused primarily by luminaires (1), reflected glare in the case of horizontal visual tasks (2) and reflected glare in the case of vertical visual tasks, e.g. at VDT workstations (3).

Glare limitation at VDT workstations: for areas with VDT workstations a cut-off angle \( \alpha \) of at least 30° is recommended.

Standards

By projecting the field of vision onto the ceiling surface it is possible to define the area in which the luminaires may have a negative influence on contrast rendering.

Standards exist for the lighting of workplaces, which stipulate minimum cut-off angles or highest permissible luminances in the cut-off range. For workstations with VDTs there are specific requirements. The critical area can be defined as that portion of the ceiling which is seen by the user in a mirror covering the working area. In the case of luminaires with mirror reflectors direct glare control improves the greater the cut-off angle. The standard cut-off angles are 30° and 40°.

The UGR (Unified Glare Rating) process is used to evaluate and limit the direct discomfort glare in indoor areas. The UGR value is influenced by the light source’s luminance, its visible size (solid angle) and its position (position index), as well as the luminance of the background. It is usually between 10 and 30. The smaller the UGR value, the less the glare.
Guide

Designing with light  |  Practical planning  |  Luminaire selection

Illuminance

<table>
<thead>
<tr>
<th>E (lx)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>20-50</td>
<td>Paths and working areas outdoors</td>
</tr>
<tr>
<td>50-100</td>
<td>Orientation in short-stay spaces</td>
</tr>
<tr>
<td>100-200</td>
<td>Workrooms that are not in continuous use</td>
</tr>
<tr>
<td>200-500</td>
<td>Simple visual tasks</td>
</tr>
<tr>
<td>500-750</td>
<td>Visual tasks of average degree of difficulty</td>
</tr>
<tr>
<td>750-1000</td>
<td>Difficult visual tasks, e.g. office work</td>
</tr>
<tr>
<td>2000-3000</td>
<td>Complicated visual tasks, e.g. precision assembly work</td>
</tr>
<tr>
<td>≥ 2000</td>
<td>Extremely complicated visual tasks, e.g. inspection and control</td>
</tr>
</tbody>
</table>

Recommended illuminance level

E according to CIE for various activities

Visual performance generally improves sharply as the illuminance level is increased. Above 1000 lux, however, it increases more slowly, and at extremely high illuminance levels it even starts to decrease due to glare effects.

However, following a set of fixed rules for illuminance levels gives little consideration to actual perception. It is not the luminous flux falling on a given surface – illuminance – that produces an image in the eye, but the light that is emitted, transmitted or reflected by the surfaces. The image on the retina is created entirely by the luminance pattern of the perceived objects, in the combination of light and object.
Luminaires are required to meet the safety requirements in all cases; in Germany this is usually guaranteed by the presence of a test symbol. In some cases there are other requirements that have to be met and the luminaires marked accordingly. Special requirements have to be fulfilled by luminaires that are to be operated in damp or dusty atmospheres, or in rooms where there is a danger of explosion. Luminaires are classified according to their mode of protection and protection class, whereby the protection class indicates the type of protection provided against electric shock, and the mode of protection its degree of protection against contact, dust and moisture.

### Identification of protection mode (IP):

- **code X**, foreign body protection
- **code Y**, water protection

### Protection classes

<table>
<thead>
<tr>
<th>Protection class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>The luminaire has a connection point for an earthed conductor, to which all metal parts with which users may come into contact must be connected. Connection to the mains earth conductor is imperative.</td>
</tr>
<tr>
<td>II</td>
<td>The luminaire is insulated such that there are no metal parts which users can touch that may be live if a fault occurs. There is no earth conductor.</td>
</tr>
<tr>
<td>III</td>
<td>The luminaire is operated on low-voltage up to 42 V, supplied via safety transformer or batteries.</td>
</tr>
</tbody>
</table>

Special requirements to fire safety have to be fulfilled when luminaires are installed in or on furniture or other inflammable materials.

- Luminaire suitable for mounting on parts of buildings comprising materials with an ignition point of >200°C
- Luminaire with a limited surface temperature, suitable for installation in areas exposed to dust containing inflammable materials or in danger of explosion
- Luminaire suitable for installation in or on furniture made of standard inflammable material
- Luminaire suitable for installation in or on furniture with unknown inflammable properties
- Luminaire suitable for installation in or on furniture with unknown inflammable properties, supplied via safety transformer or batteries

**Safety distance (R) in the direction of beam**
Designing the lighting layout should not be seen as a solely technical or functional process. In quantitative lighting design, it has become preferred practice to plan the lighting layout of ceiling-mounted luminaires to produce a completely uniform grid, with the aim of providing uniformly distributed lighting. Consequently, there is no direct link between lighting layout and lighting effect; by exploiting the wide range of luminaires available it is possible to achieve a designed pattern of lighting effects using a variety of lighting layouts. The lighting design should make use of this scope, producing ceiling designs that combine functional lighting with an aesthetic lighting layout that relates to the architecture.
Floor

The recommended offset from the wall \(a\) is half the luminaire spacing \(d\). The luminaire spacing \(d\) between two adjacent structures should correspond to the height \(h\) above the floor or work surface.

Cut-off angle

The greater the cut-off angle, the greater the visual comfort provided by the luminaire due to improved glare control. The same lighting layout of downlights produces different distributions on the wall. A cut-off angle of 40° gives the best possible compromise between the necessary horizontal illuminance on the floor and vertical illuminance. Vertical illuminance is important in places such as salesrooms where products should be well illuminated. On downlights with a 30° cut-off angle, the maximum luminous flux is emitted at a high lateral angle. Due to their narrow light distribution, downlights with a 50° cut-off angle achieve very a high visual comfort for high rooms.

No light is emitted beyond the cut-off angle.
**Wall**

The distance from the wall for wallwashers should be at least one third of the room height. Alternatively, the wall offset is given by a 20 degree line extending from the base of the wall up to the ceiling. Whereas for normal room heights the luminaire spacing is the same as the wall offset, in high rooms this spacing must be reduced to compensate for the illuminance which is generally reduced. Wallwashers do not give optimum uniformity until at least three luminaires are used. A wallwasher in a room corner should be positioned on the 45° line.

**Room corner**

The recommended distance of downlights to the wall is generally half the distance between the downlights. Corner-mounted luminaires should be mounted on the 45° line to produce identical scallops on both walls.

**Mirrored walls**

For mirrored walls, the lighting layout should be chosen such that the pattern continues uniformly in the reflection.
Wall element

In spaces with dominant architectural features, the lighting layout should harmonise with the architectural elements.

Ceiling

Ceiling lighting requires sufficient room height to achieve even light distribution. Ceiling washlights should be mounted above eye-level to avoid direct glare. The ceiling offset depends on the degree of evenness required and should generally be 0.8m.

Object

Objects can be illuminated with light directed from between 30° to 45° to the vertical. The steeper the incident light, the more pronounced the three-dimensionality of the illuminated object. If the angle of incidence of the light is approximately 30°, the so-called “museum angle”, this produces maximum vertical lighting and avoids reflected glare that may disturb the observer. In the case of reflecting surfaces, e.g. oil paintings or pictures framed behind glass, attention must be paid to the angle of incidence of the light to avoid disturbing reflections that may arise in the observer’s field of vision. This will also avoid any heavy shadow, e.g. picture frame shadows on the picture.
Horizontal surfaces

High luminance values reflected by surfaces or objects cause secondary glare. The luminaires should not be positioned in critical areas. Indirect illumination with diffuse light reduces the secondary glare. The beam should be aimed such that shadows on the work surface are avoided.

Vertical surfaces

If a reflective surface is arranged transversely, luminaires can be mounted in front of the excluded ceiling zone. If a reflective surface is arranged vertically, they can be mounted next to the excluded ceiling zone.
Point source

The simplest layout of these points is a regular grid, in a parallel or staggered arrangement. A regular pattern of identical luminaires can easily result in a monotonous ceiling appearance, plus the fact that differentiated lighting is practically out of the question.

Point sources: regular and staggered layouts

Point source combinations

An alternating grid of different individual luminaires or luminaire combinations can produce more interesting arrangements; in this case luminaires of the same or different types can then be purposefully combined.

The point sources may be luminaires of different shapes and sizes, or compact groups of luminaires.
A further step towards more complex design forms is the linear arrangement of point sources. In contrast to simple lighting layouts in grid patterns, the ceiling design in this case relates more closely to the architecture of the space. The ceiling is designed along the lines dictated by the architectural form of the space. This may involve following existing lines or purposefully arranging the luminaires in contrast to the existing formal language.

Since the linear arrangement of the luminaires does not necessarily relate to an actual line such as the course of a wall, ceiling projections or joists, the luminaire arrangement can only be created on the basis of the perception of gestalt. These laws of gestalt must receive special attention during the planning phase. The crucial criteria are the equidistance and proximity of luminaires to each other.

Luminaire arrangements can follow existing architectural structures or create patterns of their own.
Whereas linear arrangements consisting of a series of points are only produced indirectly by our perception of the gestalt, they can also be directly formed of linear elements. These linear elements can be particular types of luminaires, or even trunking systems. Light structures and track arrangements or other trunking systems belong to this design category. The formal language of linear arrangements is identical to that of rows of points. As the visual forms produced when linear luminaires are used are real and not just implied, more complex arrangements can be planned with no danger of distortion through perception.

Creative design allows both the alternating application of different luminaire forms and the use of spotlights on lighting structures or trunking systems. This allows differentiated lighting without the individual luminaires disturbing the intrinsic appearance of the structure.
Decorative solutions

The combination of different elements gives rise to a broad range of design possibilities, including decorative solutions.

Linear structures

The rectangular arrangement of tracks corresponds to the shape of the room. This allows flexible lighting of all wall surfaces and accentuating of objects in the space.
Both technical and design aspects are important when mounting. If the arrangement of the luminaires is already fixed, then the focus shifts to the mounting detail. Various mounting versions are available for downlights, e.g. surface-mounting, recessed-mounting or pendant suspension.
Suspended ceilings

In the case of flat suspended ceilings, e.g. plasterboard ceilings, the luminaires can almost always be arranged irrespective of the suspended ceiling grid. The luminaires are fixed firmly in the ceiling apertures provided; if necessary, the weight of the luminaire must be carried by additional suspensions fixed onto or in close proximity to the luminaire. If the ceiling is to be plastered, plaster rings are required for the luminaire apertures.

Panel ceilings

For open grid ceilings and honeycomb-grid ceilings there are recessed cassettes available complete with suitable apertures for the recessed mounting of downlights. The cassettes are dimensioned to suit the respective ceiling grids. They can replace a ceiling panel or allow the installation of luminaires between ceiling panels which would otherwise not be suitable to take the static load.

Ceiling channel

Light sources can be mounted in a track ceiling channel in order to integrate them invisibly into the ceiling.
Pendant luminaires

Pendant mounting can be effected in a variety of ways. Light-weight luminaires are usually suspended by the connecting cable. Heavier luminaires require a separate suspension device. This may take the form of a stranded wire cable or a pendant tube, which generally contains the connecting cable.

Concrete ceilings

For recessed mounting into concrete ceilings the luminaire apertures are created when the ceiling is cast. Another possibility is to install prefabricated housings, which are also attached onto the concrete shuttering and remain in the ceiling. It is essential to check that the planned lighting layout is compatible with the structure of the ceiling, whether specific installation locations must be avoided, for example, due to concealed joists or whether the reinforcement of the ceiling should be co-ordinated with the lighting layout.
Wall

Luminaires can be mounted onto wall surfaces or recessed into the wall. The latter can be in either concrete or hollow walls. Luminaires can be mounted on wall brackets or cantilever arms for indoor partitions or outdoor facades.

Floor

Luminaires for floor or ground installation can be surface-mounted or recessed-mounted. When recess-mounted in the floor or ground, the luminaire cover must be robust and provide protection against the ingress of moisture. Bollard luminaires and mast luminaires may also be used outdoors.
By stipulating a light loss factor when planning the lighting, the intervals at which maintenance is to be carried out can be controlled. By keeping light loss factors low, the lighting level will initially be higher and the period during which luminous flux is gradually reduced to below the critical value will be extended. Using a suitable maintenance factor, lamp replacement and the cleaning of luminaires can be timed to take place simultaneously. The adjustment of luminaires is also classified as maintenance in the interest of the qualitative aspects of the lighting installation. In the area of display lighting in particular, luminaires have to be realigned to accommodate the layout of a new arrangement. A maintenance plan should enable the operator to service the installation at regular intervals, checking whether the technical requirements are being met and the lighting is performing as planned.
Representing lighting installations and their lighting effects in architecture plays a key role in lighting design. The range of representations includes the whole gamut from technically oriented ceiling plans to graphic illustrations of varying complexity to computer-calculated room representations and three-dimensional models of architecture or lighting installations. Skilled lighting designers use ceiling plans and diagrams to derive a realistic idea of the lighting effects achieved. Others in the planning process with less expertise have to rely on visual representations and technical specifications.
The graphic methods employed extend from simple sketches to detailed and elaborate processes. The more elaborate the method used, the more accurate is the representation of the illuminated environment and the lighting effects. Perspective room representations include the positioning of the lighting equipment in the room.
In the simplest case, lighting effects can be shown in a graphic format by light beams designed either as contours, as coloured surfaces or in grey tones contrasting with the background. Drawings that show light beams using light, coloured pencils or chalk on a dark background achieve an intense luminosity and are particularly useful for representing outdoor lighting at night. When visualising an overall concept, a deliberately simplified sketch can demonstrate the lighting effects produced more effectively than an allegedly realistic representation with artificially scaled brightness ratios.
Using rough sketches for visualisation, the story board acts as a creative script detailing the spatial and temporal progression of the lighting effects. It is an effective tool in scenographic lighting design to look at the dynamic processes in the building. These processes result from aspects such as the spatial progression encountered as you walk through the building, but also from the time dimension experienced in a room throughout the course of a day.
The mood board is a collection of pictures, sketches, materials, colours, and terms to describe emotions. Where different moods are required as special effects in a room, parallel collages with diverse themes can be used to underline the statements on contrasts and colours for the different light scenes. While the mood board initially focuses on a broad collection of pictures, the process of evaluation and concentration is more analytical.
Technical drawings provide exact information on the type and positioning of the luminaires used in the ceiling plan and the sectional drawing. For spotlights, for example, the drawing can also specify the alignment of the luminaires. For a better overview, a table can be used to list all the luminaires with their symbols and features. The electrical designers also require details on circuits, switches, push-buttons and protection modes.

Diagrams can be used to document aspects such as the illuminance or luminance distribution in a room. In the Isolux diagrams, contours indicate the same illuminances, while the contours in Iso-candela diagrams specify the luminances.
While the spatial representations of simulation programs reproduce the illuminance levels in a room by way of diagrams, they also provide a visual impression of the lighting concept. In contrast to the drawing, the computer graphic furnishes objective information, as it is based on precise calculations.
Qualitative simulation

The light simulation for qualitative representations focuses on portraying atmosphere. The spatial perspective provides an accurate impression useful for the presentation of the lighting design. The degree of detailing can include photorealistic illustrations.

Quantitative simulation

The quantitative simulation is used for the analysis of a lighting design. It determines the physically correct numerical values for specific visual tasks. The simulation also helps to check compliance with requirements specified in standards, such as uniformity of illuminance. A further effective visualisation method is false-colour diagrams which allow levels to be represented through a colour scale.

Animation

Animation combines individual images generated through simulation to produce a film. It is ideal to demonstrate dynamic lighting effects. Animations where either the camera angle remains the same but the lighting changes or the lighting stays the same but the camera is moved are comparatively simple. Animations where both the lighting and the camera position change are far more complex since each individual image of the film has to be recalculated. The alternative is to use special video post-editing processes.
One of the significant advantages resulting from the use of models is that light is not just represented but becomes effective. Lighting effects are visualised in all their complexity, not merely schematised. A further advantage of models is the aspect of interaction in that the observer can accurately check every angle. A distinction has to be made here between a working model and a presentation model.
Size and accuracy limit the informative value of the simulation and should be determined accordingly. The scale ranges from 1:100 or 1:200 for the daylight effect of whole buildings to scales of 1:20 to 1:10 for differentiated lighting effects in individual areas. The most critical factor, specifically when using very small-scale models, is usually the size of the luminaires themselves. Variations in the light intensity distribution are clearly reflected in the result. The accuracy of luminaire reproductions is limited on account of the dimensions of the light sources available. The result is that designers often use light guide systems from an external light source to simulate the output from several luminaires.

A mock-up is a reproduction of a room situation at a scale of 1:1. A mock-up of the luminaire or the architectural space concerned is ideal as a basis for decisions specifically when assessing customised luminaires or luminaires which are to be integrated into the architecture. To limit the effort involved, a mock-up is based on an architectural section for maximum benefit.
Daylight simulation

In the simplest case, both the sun and the daylight can be used directly in outdoor scenes or else be reproduced exactly using a solar simulator or an artificial sky. When simulating sunlight outdoors, a sundial-type display instrument is used to position the model at precisely the angle of incidence of the light that corresponds to a specific season and time of day. In the solar simulator, this is performed by a movable, artificial sun. Both methods allow reliable studies of the lighting effects in and around a building and of engineering designs for daylight control or sun protection even for small-scale models.

Cameras are used to capture these observations and to document the lighting changes throughout the day or year. The artificial sky is used to simulate the lighting conditions on a cloudy day and to take measurements of the daylight ratio.
Light determines the mood of a room. Lighting applications and the corresponding lighting effects of different luminaires are rehearsed using simulations and architectural examples.
The effect of rooms, areas and objects greatly depends on the type of lighting. This ranges from uniform washlighting through to highlighting and the projection of gobo images.

- General lighting
- Accentuation
- Washlighting
- Wallwashing
- Projection
- Orientation lighting
Guide

Indoor lighting | Types of lighting

General lighting

Ambient lighting produced by wide beam light distribution facilitates perception and orientation in the horizontal plane. As direct or indirect lighting, it produces a directed or diffuse light to illuminate workplaces or traffic zones.

direct, aimed
direct, diffuse
indirect

direct and indirect
Direct and aimed general lighting produces an even illumination on the horizontal working plane. The architecture is visible and it is possible to orientate oneself and work in the room.

The directed light produces good modelling and brilliance. The uniformity on the working plane increases as the room height increases or as the beam angle widens. Directed light enables good appreciation of form and surface texture. The visual comfort increases as the cut-off angle increases. A feature of direct illumination is its highly efficient use of energy. At the work place, secondary glare must be taken into consideration.

Applications

Projects:
City Hall, Graz
Centre Pompidou, Paris
Congress Palace, Valencia
ERCO, Lüdenscheid
Direct diffuse general lighting designates an even illumination with respect to a horizontal working plane. The architecture is visible and it is possible to orientate oneself and work in the room.
Direct diffuse light produces a soft illumination with little shadow and reflection. The limited formation of shadow results in weak modelling capabilities. Shapes and surface textures are only slightly emphasised.

Direct, diffuse general lighting for:
- working areas
- multifunctional rooms
- museums
- exhibitions
- pedestrian traffic areas

Preferred luminaire groups:
- light structures
- downlights
- wall-mounted downlights
- luminous ceilings

Projects:
Congress Centre, Valencia
Prada, Milan
German Architectural Museum, Frankfurt
Fondation Beyeler, Basel
Indirect general lighting uses a ceiling, wall or other surface as a secondary reflector. The brightening of these surfaces that delineate the room or area gives an open spatial impression.

Observation

Indirect general lighting uses a ceiling, wall or other surface as a secondary reflector. The brightening of these surfaces that delineate the room or area gives an open spatial impression.

Light structures

Uplights

The diffuse light produces limited shadows and a weak modelling. Using indirect illumination alone gives a lower spatial differentiation. Compared to direct illumination, a considerably higher luminous flux is necessary for achieving the same illuminance on the working plane. The secondary reflector should boast a high reflectance. Direct and secondary glare are extensively avoided.

Conclusion
Applications

Projects:
British Museum, London
Ezeiza Airport, Buenos Aires
Eremitage, St. Petersburg
Villa, Salzburg

The prerequisite for an even distribution of light is a sufficiently high room. Indirect illumination should be mounted above eye-level. The distance from the ceiling depends on the level of evenness required and should be at least 0.8m.

Indirect general lighting for:
- working areas
- multifunctional rooms
- pedestrian traffic areas

Preferred luminaire groups
- light structures
- uplights
Direct/indirect general lighting refers to a combination of direct and indirect illumination with respect to the horizontal working plane. The ceiling or walls serve here as reflection surfaces. The brightening of these surfaces that delinate the room or area gives an open spatial impression.

The uniformity on the working plane increases as the room height increases. Directed light enables a good appreciation of form and surface texture. The secondary reflector should boast a high reflectance. The uniformity on the ceiling increases the further away the luminaire is from the ceiling. A feature of general lighting with fluorescent lamps is its highly efficient use of energy.
Applications

Projects:
Civic Cleaning Adult-Education Centre, Berlin
Reichstag, Berlin
Palacio de la Aljaferia, Zaragoza
Fibanc, Barcelona

Direct/indirect general lighting for
- working areas
- multifunctional rooms
- pedestrian traffic areas

Preferred luminaire groups:
- light structures
- pendant downlights
Guide

Indoor lighting | Types of lighting

Accentuation

Observation

Accent light emphasises individual objects or architectural elements using narrow beams of light. Bright points in dark surroundings attract attention. They separate the important from the unimportant, allowing individual objects to come to the fore.

Spotlights

Directional downlights

Conclusion

Accent lighting enables good appreciation of form and surface structure. The focused light produces pronounced shadows and good modelling ability, as well as brilliance. A narrow beam and a high brightness contrast to the surroundings give the object particular emphasis.
Accent lighting creates points of interest and improves the local visual performance, e.g. at the work place. Structures and textures of objects are clearly emphasised by the directed light.

Accent lighting for:
- exhibitions
- museums
- sales and presentation areas
- restaurants, cafés, wine bars
- working areas

Preferred luminaire groups:
- spotlights
- contour spotlights
- directional downlights
- directional recessed floor luminaires
- task lights
Washlighting illuminates larger objects or spatial zones using wide beam light distribution. In contrast to accent light, it conveys a wide impression.

Observation

The directed light produces good modelling abilities and enables good appreciation of form and surface structure. Washlighting illumination can serve as a background for accent lighting.

Conclusion

Mounting floodlights on tracks allows a flexible positioning of the luminaires.

Washlighting illumination for:
- exhibitions
- museums
- sales and presentation areas
- multifunctional rooms
Preferred luminaire groups
- floodlights

Applications

Projects:
Catedral de Santa Ana, Las Palmas
Passeig de Gràcia, Barcelona
Royal Armouries Museum, Leeds
Museo ‘Fournier’ del Naipe, Vitoria
Vertical illuminance defines and structures spatial situations. It makes a significant contribution to the impression of brightness in a space and to a feeling of security.
Uniform wallwashing defines the spatial environment. A uniform brightness distribution from ceiling to floor emphasises walls as a whole. Wallwashing with a high degree of uniformity is ideal for museums to illuminate artwork, in salesrooms for shelf lighting or in foyers to create the impression of a wide and representational space.

Wallwashing with focal emphasis complements the uniform wallwashing by adding a highlight in the upper third of the illuminated wall. This type of lighting is suitable, for instance, for the efficient illumination of displays above shelving in salesrooms.

Wallwashing for corridors provides highly uniform illumination for two parallel running walls. The uniform illuminance distribution from ceiling to floor conveys a wide impression. The clear structure of the room facilitates orientation. Wallwashing for corridors is particularly suited for halls and passageways in hotels, administrative buildings or health and care facilities.
Wallwashing with ambient lighting complements the uniform wallwashing by adding horizontal ambient lighting. This type of lighting forges a link between the vertical illuminance on the surrounding surfaces and the ambient lighting provided by downlights in the centre of the room. In salesrooms, both shelves and tables in front of the wall can be illuminated.

Grazing light emphasises the material and surface texture of walls. Positioning the luminaire close to the wall produces a graduation of brightness on the vertical axis. Grazing light impressively brings out the texture of natural stone or wood.
Observation

Projectors are used for projecting signs, patterns and images using gobos or structured lenses for light effects and to create sharp-edged patterns. This enables an additional level of information and awareness to be built up.

Interesting effects can be created using gobos and filters.

Conclusion
Guide

Indoor lighting | Types of lighting

Projection

Applications

- exhibitions
- museums
- sales and presentation areas
- restaurants, cafés, wine bars
- hotels

Projections can be made with:
- spotlight projectors

Projects:
- Aragon Pavillon, Sevilla
- Hannover Messe
- Teatri Ravintola, Finland
- ERCO, Lüdenscheid
Orientation lighting improves perception by adding light points and lines, e.g. along pathways and on stairs. The light must function as a signal. Illuminating the room is of secondary importance here.

Observation

Floor washlights

Wall-mounted downlights

Recessed floor luminaires
 Orientation lighting

Low illumination levels are sufficient for orientation purposes. Small luminaires with high luminance clearly set themselves apart from their surroundings. Orientation lighting improves orientation in complex buildings and makes it easier to find fire exits in emergencies.

Conclusion

Applications

Projects:
Light and Building, Frankfurt
Palazzo della Ragione, Bergamo
Hilton Hotel Dubai

Orientation lighting for the identification of
- architectural lines
- steps and exclusion zones
- entrances
- routes
- emergency exit routes

Preferred luminaire group
- floor washlight
- wall-mounted downlights
- recessed floor luminaires
- orientation luminaires
Luminaires are available in a wide variety of types, each intended to fulfil different lighting requirements. The same light distributions can be achieved with different luminaires. The choice depends on whether the luminaires are to be a design feature in their own right, or whether an integrative design approach is being followed. Compared to luminaires that are permanently mounted, track-mounted luminaires offer a higher degree of flexibility.
Tracks form the basis for a variable and flexible lighting design that can orientate itself around the changing interior design and usage of a room. Mating adapters on the luminaires perform both the electrical and mechanical connection.

Tracks provide a flexible form of voltage supply for spotlights, floodlights and wallwashers, for accent lighting and washing of all professional lighting situations. Using multiphase tracks makes it possible to operate different circuits simultaneously. Recessed tracks are inconspicuous architectural details. The tracks can also be suspended via pendant tubes or wire rope. They should correspond to the architecture in their arrangement and form.

Projects:
Teatri Ravintola, Helsinki
Christie’s Showroom, New York
Caras Gourmet Coffee Kranzler-Eck, Berlin
Kayser private home, Neuenrade
Light structures are luminaires that additionally allow the possibility for attaching mobile luminaires, often using integrated tracks or singlets. Light structures consist of a tubular or panel elements and are usually suspended from the ceiling. First and foremost, light structures use elements with integrated luminaires for linear light sources that can be used both for direct general lighting and for indirect lighting with light reflected by the ceiling. Elements with integrated downlights or directional luminaires provide accent lighting.

### Luminaires Direct
Light structures with direct light have an axially symmetric light distribution emitted downwards for illuminating the usable surfaces.

### Luminaires Indirect
Light structures with indirect light distribution have an axially symmetric light distribution emitted upwards for illuminating the ceiling.

### Luminaires Direct/Indirect
Light structures with direct/indirect light distribution have an axially symmetric light distribution emitted upwards and downwards for illuminating the usable surfaces and the ceiling.
Applications

Projects:
Reichstag, Berlin
Xaverian Brothers High School, Westwood MA
Regional Govt., Berlin
Shanghai Museum

Arrangement

General lighting in:
- offices, medical practices
- pedestrian traffic areas
- additional accent lighting and washlighting with the help of spotlights, floodlights and wallwashers

The offset from the wall (a) is recommended as being half the luminaire spacing (d). The luminaire spacing (d) between two neighbouring structures should correspond to the height (h) above the floor or work surface. The distance to the ceiling depends on the level of evenness required on the ceiling. The distance to the ceiling should measure at least 0.8 m for indirect lighting so that an even illumination is ensured.
The mounting location and the orientation are variable. Spotlights are offered with different beam emission angles and light distributions.

Criteria for spotlights
- choice of lamp determines light colour, brilliance, functional life, light intensity
- emission angle determines the beam of light and is defined by the reflector
- cut-off angle limits glare and increases visual comfort
- rotatable and tiltable
- accessories: lenses, filters; glare control

Spotlights
Spotlights have a narrow-beam (spot approx. 10°) to wide-beam (flood approx. 30°) light distribution with a rotationally symmetrical beam.

The use of accessories is also typical for spotlights:
- lenses: spread or sculpture lenses
- filters: - filters: colour filters, ultraviolet or infrared filters
- barn doors, dazzle cylinders, multigroove baffles or honeycomb anti-dazzle screens

Contour spotlights
Contour spotlights with lenses for projection for various beam emission angles.
Some types of spotlight are equipped with convex lenses or Fresnel lenses for a variable beam angle. In addition, spotlights with image contouring or projecting systems (contour spotlights) enable different beam contours or projected images by projecting through apertures or stencils (gobos).
Guide

Indoor lighting | Luminaire groups
Spotlights

Arrangement

On pictures on walls or objects in a room, the light should be incident at an angle of less than 30°.

Applications

For highlighting or projection in:
- museums
- exhibitions, art galleries
- sales rooms
- presentation and display areas

Since they enable variable mounting locations and orientation, spotlights can be adapted to suit changing tasks. A narrow light distribution enables smaller areas to be illuminated, even from a larger distance. Conversely, the wide light distribution of projector floodlights enables a larger area to be illuminated with a single luminaire. Gobos and structured lenses are used to project lighting effects. In addition, filter foils can also be used.

Projects:
Christie’s Auctioneers, New York
Gmurzynska Gallery, Cologne
Bunkamura Museum of Art, Tokyo
Expo Seville, Spain
**Light**

Floodlights feature a wide-beam characteristic. They are offered with a predominantly symmetrical light distribution.

Criteria for floodlights
- choice of lamp determines light colour, brilliance, functional life, efficiency, light intensity
- uniformity: optimised reflector for even illumination of areas
- gradient: soft edge to the beam of light
- light output ratio is increased by optimised reflector technology

**Applications**

Projects:
- Catedral de Santa Ana, Las Palmas
- Passeig de Gràcia, Barcelona
- Royal Armouries Museum, Leeds
- Museo ‘Fournier’ del Naipe, Vitoria

Floodlights provide even illumination of areas or objects for:
- museums
- exhibitions
- trade-fair stands
- sales areas
- presentational areas

The luminaires should correspond to the architecture in their arrangement and form.
Guide
Indoor lighting | Luminaire groups

Wallwasher

Wallwashers have a wide-beam characteristic. They are offered with an asymmetric light distribution.

Criteria for wallwashers
- choice of lamp determines light colour, brilliance, functional life, light intensity
- uniformity: optimised reflector for even illumination of areas
- gradient: soft edges to the beam
- light output ratio is increased by optimised reflector technology

Wallwashers (spotlights)
Wallwashers have an asymmetric light distribution for evenly illuminating wall faces. Track-mounted wallwashers allow the luminaire spacing to be flexibly adjusted as required.

Wallwashers, tiltable (spotlight)
Spotlights with wallwasher attachment feature a asymmetric light distribution for evenly illuminating wall surfaces. Track-mounted wallwashers allow the luminaire spacing to be flexibly adjusted as required. Wallwashers with kick-reflector have an asymmetric light distribution for evenly illuminating wall faces.

Washlights
Wallwashers have an asymmetric light distribution for evenly illuminating wall faces. In addition, they also feature a downlight component for evenly illuminating the floor.
**Double-focus wallwashers**
Double-focus wallwashers have an asymmetric light distribution for evenly illuminating wall faces. The shielding of the lamp provides high visual comfort and prevents the emission of spill light. The homogeneity of the wallwashing is particularly high.

**Lens wallwashers**
Lens wallwashers have an asymmetric light distribution for evenly illuminating wall faces. The lens serves to spread out the beam.
Wallwasher

The offset from the wall for wallwashers should not be less than one third of the wall height. This corresponds to an angle of at least 20°. The optimal ratio of wall offset to luminaire spacing for avoiding evenly illumination is 1:1. Independent of the actual room height and offset from the wall, tiltable luminaires must be aligned on the lower part of the wall.

Wallwashing is an important component of architectural lighting for adding emphasis to room areas and for illuminating higher, vertical faces or wall areas for:
- museums
- exhibitions
- trade-fair stands
- auditoriums
- halls in public buildings and shopping malls
- sales areas
- presentational areas

Surface-mounted luminaires act as a feature in the room. They should correspond to the architecture in their arrangement and form.

Projects:
British Museum, London
Crescent House, Wiltshire
Mediathek, Sendai
Weimar College of Music
Recessed spotlights, recessed floodlights and recessed wallwashers

**Light**

Recessed spotlights, floodlights and wallwashers emit a beam that is directed downwards or to the side. They are offered with narrow-beam, wide-beam, symmetrical or asymmetrical light distribution. This type of lighting combines the flexibility of spotlights with the discreet appearance of recessed luminaires.

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**Recessed spotlights**
Recessed directional luminaires provide highlighting for individual areas or objects with a narrow to medium light distribution.

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**Recessed floodlights**
Recessed floodlights produce a wide-beam light distribution for washlight illumination of objects in the room or on the wall.

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**Recessed wallwashers**
Recessed wallwashers have an asymmetrical beam that is directed onto vertical surfaces. They provide an even illumination for wall surfaces.
Guide

Indoor lighting | Luminaire groups

Recessed luminaires

**Light**

Downlights emit a beam that is directed downwards at either a perfectly vertical or an adjustable angle. They are offered with narrow-beam, wide-beam, symmetrical or asymmetric light distribution.

**Criteria for downlights**
- choice of lamp determines light colour, functional life, efficiency, light intensity
- emission angle determines the beam of light and is defined by the reflector
- cut-off angle limits glare and increases visual comfort
- light output ratio is increased by optimised reflector technology

**Double-focus downlights**

Double-focus downlights have a rotationally symmetric beam that is directed vertically downwards. On double-focus downlights, a special reflector shape enables a high luminous flux even for smaller ceiling apertures.

**Downlights**

Downlights have a rotationally symmetric beam that is directed vertically downwards.

**Washlights**

Washlights have an asymmetric beam that is directed vertically downwards and onto vertical surfaces. They provide an even illumination for wall and floor surfaces. Special forms are double washlights for illuminating two opposite wall sections and corner washlights for illuminating corners of rooms.

The cut-off angle of narrow-beam downlights makes them a highly glare-free light source. On downlights with Darklight reflector, the lamp’s cut-off angle is identical to that of the luminaire. This gives a luminaire with the widest beam possible while simultaneously having an optimised light output ratio. The use of a diffuser reduces the luminance in the luminaire and thereby improves the visual comfort.
Double-focus wallwashers

Double-focus wallwashers have an asymmetric light distribution that is directed at vertical surfaces. They are used for illuminating wall surfaces evenly. Double-focus wallwashers are fitted with special, internal wallwasher segments. With this special kind of reflector technology the lamp is hidden from the direct view of the observer at all times.
**Directional luminaires**

Directional downlights are used for highlighting individual areas or objects with a medium to narrow light distribution.

The offset from the wall should measure at least one third of the room height. Alternatively, the offset from the wall is where a 20° degree line projected upwards from the base of the wall intersects the ceiling. An optimum evenness is obtained when the luminaire spacing is the same as the offset from the wall, or at least does not exceed it by more than 1.5 times. Wallwashers only develop their optimal evenness as of a minimum number of three luminaires. The position of a wallwasher in a corner of a room should lie on the 45° line.

The offset from wall should measure approximately half of the luminaire spacing in order to achieve sufficient brightness on the wall and well proportioned scallops of light. To attain an even illumination on a reference plane, the luminaire spacing should not exceed the mounting height $h$ by more than 1.5:1. An optimal evenness is achieved when $d = h$. To obtain symmetrical scallops in a corner, one downlight must be positioned on the 45° diagonal.

**Arrangement**

**Downlights**

**Wallwashers**
Applications

Projects:
Pleats Please Issey Miyake Store, Bangkok
British Museum, London
Centre Pompidou, Paris
Armand Basi Shop, Barcelona

Downlights are a universal instrument for functional, architectonic and accentuating lighting.

Recessed downlights are inconspicuous architectural details, whereas surface-mounted downlights and pendant downlights act as features in the room. They should correspond to the architecture in their arrangement and form.
Surface-mounted luminaires emit a beam that is directed downwards or to the side. They are offered with narrow-beam, wide-beam, symmetrical or asymmetrical light distribution. Surface-mounted luminaires are used where there is not enough room to install conventional recessed luminaires or for subsequent mounting in existing buildings to reduce the level of installation work.

Criteria for surface-mounted luminaires
- choice of lamp determines light colour, functional life, efficiency, light intensity
- emission angle determines the beam of light and is defined by the reflector
- cut-off angle limits glare and increases visual comfort
- light output ratio is increased by optimised reflector technology

Surface-mounted downlights
Downlights have a rotationally symmetrical beam that is directed vertically downwards.

Surface-mounted wallwashers
Surface-mounted wallwashers with asymmetrical light distribution provide an even illumination of areas.

Surface-mounted double washlights
Surface-mounted double washlights with asymmetrical light distribution provide an even illumination of areas.
Pendant luminaires emit a beam that is directed downwards. The pendant suspension system allows adjustment of the height of the light source for optimum glare control for tables or in rooms with high ceilings.

Criteria for pendant luminaires
- choice of lamp determines light colour, functional life, efficiency, light intensity
- emission angle determines the beam of light and is defined by the lighting technology
- cut-off angle limits glare and increases visual comfort
- light output ratio is increased by optimised reflector technology
Wall-mounted downlights are defined first and foremost by their type of mounting and not by their light characteristics. Different light distributions are possible such as narrow-beamed, wide-beamed, symmetrical or asymmetrical in various directions.

Criteria for wall-mounted downlights:
- choice of lamp determines light colour, functional life, efficiency, light intensity
- emission angle determines the beam of light and is defined by the reflector
- cut-off angle limits glare and increases visual comfort
- light output ratio is increased by optimised reflector technology

Ceiling washlights
Ceiling washlights have an asymmetric light distribution and emit light upwards onto horizontal surfaces. The ceiling surface is illuminated evenly and over a large area. On ceiling washlights, the section of the ceiling to be illuminated can be partly clipped along the luminaire’s main axis with the help of infinitely adjustable cut-off shields. Uplights differentiate themselves from ceiling washlights by their different reflector geometry, altered light distribution, and higher light output ratio.

Floor washlights
Floor washlights have an asymmetric light distribution and emit light downwards onto horizontal surfaces.
Ceiling washlights should be mounted above eye-level. The distance to the ceiling depends on the level of evenness required on the ceiling. The distance to the ceiling should measure at least 0.8 m for indirect lighting so that an even illumination is ensured.

The mounting height (h) of floor washlights near to seats or seating should be less than eye-level (1.2 m), normally 0.8 m above the floor level.

For illumination of ceilings or floors in:
- churches
- theatres
- museums
- pedestrian traffic areas

Recessed wall-mounted downlights are inconspicuous architectural details, whereas surface-mounted downlights act as a feature in the room. They should correspond to the architecture in their arrangement and form.

Projects:
- Citibank, Paris
- Museo de Historia, Barcelona
- Hilton Hotel Dubai Creek
- Light and Building, Frankfurt
Recessed floor luminaires emit their beam upwards. They are offered with narrow-beamed, wide-beamed, symmetrical or asymmetrical light distribution.

Criteria for recessed floor luminaires:
- choice of lamp determines light colour, service life, efficiency and light intensity
- uniformity: optimised reflector for even illumination of areas
- range of tilt for directional luminaires with high glare protection
- light output ratio is increased by optimised reflector technology

Uplights
Uplights feature an upwards directed beam with symmetrical light distribution. The narrow, rotationally symmetrical beams are used for highlighting objects.

Directional luminaires
Directional luminaires are used for highlighting individual areas or objects with a medium to narrow light distribution. The beam can be tilted.

Uplight, diffuse
Recessed floor luminaires with diffuse light intensity distribution are used for marking paths or emphasising architectural lines.
Applications

Projects:
Hotel Palais Coburg Residenz, Vienna
Centro de Historia de Zaragoza, Zaragoza
The Aldrich Contemporary Art Museum, Ridgefield
Bar Library, Belfast

Accent lighting or floodlighting for:
- theatres
- presentational areas
- sales areas
- reception and entrance areas
- architectural features

Recessed floor luminaires are inconspicuous architectural details. They should correspond to the architecture in their arrangement and form.
The defining feature of orientation luminaires is that they are designed first and foremost to provide orientation. Such luminaires may also function as sources of illumination or as signals.

Criteria for orientation luminaires:
- luminance: noticeability of the luminaires in their surroundings

Orientation luminaires, local
Orientation luminaires with point-form front lens act as a local orientation light.

Floor washlights
Floor washlights form points of light on the wall and serve as an orientation light on the floor surface.

Applications
For identifying:
- architectural lines
- steps or restricted areas
- entrances
- routes
- emergency exit routes

Projects:
Sevens department store, Düsseldorf
Hilton Hotel, Dubai
Instituto Frances, Barcelona
Hilton Hotel, Dubai
Directive luminaires provide information or give directions by way of pictograms or texts. Emergency lighting refers to luminaires that indicate the escape route to improve orientation in emergency situations.

Criteria for emergency lighting and directive luminaires:
- Luminance: noticeability of the luminaire in its surroundings
- Form and colour: to comply with the standards
- Luminaire position: to describe correctly the escape route
- Emergency power supply
- Effectiveness: to continue lighting signs upon mains power failure

Emergency lighting and directive luminaires can be subdivided into three groups:
- Directive lighting: pictograms or texts providing information
- Emergency lighting: lighting for escape routes, anti-panic lighting and emergency lighting for work places with special hazards
- Backup lighting: takes over the function of providing artificial lighting for maintaining operations over a limited period

For identifying:
- Exits
- Emergency exits, fire exits
- Escape and rescue routes

Directive luminaires are often secondary lighting features and should match with the architecture. Luminaires that change colour allow controllable dynamic route markings. Safety and rescue sign luminaires must comply with the regional guidelines.

Projects:
- Palazzo della Ragione, Bergamo
- Potsdamer Platz, Berlin
- Norwegian Aviation Museum, Bodo
- GIRA, Radevormwald
Light plays a central and multifaceted role in the design of a visual environment. In addition to the requirements and demands made by the user on lighting design, the architectonic concept also stipulates a framework for the design of the illumination.

Working plane  Wall  Ceiling

Floor  Object  Orientation lighting

Directive lighting
Illuminating a horizontal surface is one of the most common lighting tasks. Most of the lighting tasks governed by workplace standards and standards for pedestrian traffic routes come under this category, whether these be the illumination of work surfaces or the actual floor.
Observation

Demanding visual tasks not only require general lighting but also additional lighting for the workstation. With task lights, the light can be directed to the task in hand. Light structures with fluorescent lamps emit diffuse light. Directional luminaires emit an accentuating light onto the workstation. Indirect light with uplights lends the room general background lighting.

Task light

Light structure

Directional luminaire

Conclusion

To provide an energy efficient lighting, the general lighting can be lower than the illumination of the working area. Combined lighting with direct and indirect components provides good visual comfort both in the room and on the work surface.

Lighting criteria for task lighting:
- illuminance level dependent on activity
- illuminance distribution for avoiding direct- and secondary glare
- cut-off angle and position of the luminaire restrict glare and increase visual comfort
- the choice of lamp determines the light colour and colour rendition
Arrangement

High luminances reflected from surfaces or objects cause secondary glare. The luminaires should not be positioned in the critical areas. Indirect illumination with diffuse light reduces the secondary glare. When aiming the beam of light, care should be taken to avoid shadows on the work surface.

Applications

The quantitative lighting criteria are primary considerations for task lighting. Energy can be saved by reducing the general lighting in favour of local task lighting and daylight dependent control.

Preferred luminaire group
- task lights
- light structures
- directional luminaires

Projects:
Shanghai Museum
Success advertising agency
Palacio de la Aljaferia, Zaragoza
Fibanc, Barcelona
Usable areas can be illuminated directly and indirectly: downlights and pendant downlights emit direct illumination into the room. Light structures have a diffuse light distribution. Uplights illuminate the room indirectly with a diffuse, uniform light.
**Conclusion**

Compared to indirect lighting with diffuse light, the direct aimed light results in better modelling capability. Combined lighting with direct and indirect components ensures good visual comfort both in the room and on the work surface.

**Lighting criteria for usable areas:**
- Illuminance level dependent on activity
- Luminance distribution to avoid direct and secondary glare
- Cut-off angle and position of the luminaire restrict glare and increase visual comfort
- The choice of lamp determines the light colour and colour rendition

**Applications**

The quantitative lighting criteria are paramount considerations for lighting usable areas.

**Applications**
- Office workstations
- Conference rooms
- Workshops and shopfloors
- Reception and entrance areas

**Preferred luminaire groups**
- Light structures
- Downlights
- Uplights

**Projects:**
- Dansk Design Center, Copenhagen
- DZ Bank, Berlin
- Fibanc, Barcelona
- Fondation Beyeler, Basel
Under consideration of the energy aspects, direct lighting with permanently mounted downlights are the most suitable for large rooms.

**Observation**

Whereas downlights represent fixed-location general lighting, spotlights can be used flexibly in the area of exhibitions and presentations. Due to their narrow-beam light distribution, spotlights have high glare control. Directed light results in good modelling capabilities.

**Conclusion**

Lighting criteria for usable areas:
- illuminance level, depending on the activity
- luminance distribution to avoid direct and secondary glare
- cut-off angle and position of the luminaire restrict glare and increase visual comfort
- the choice of lamp determines the light colour and colour rendition
Applications

Projects:
Reichstag, Berlin
Bank of China, Beijing
ERCO, Lüdenscheid
Ständehaus art gallery, Düsseldorf

The quantitative lighting criteria are paramount considerations for lighting usable areas. Direct illumination here is considerably more economical than indirect illumination.

General lighting for
- workshops and shopfloors
- museums
- exhibitions
- sales and representational areas

Preferred luminaire groups
- downlights
Wall lighting can fulfill a number of tasks. Firstly, it can be aimed at fulfilling vertical visual tasks on the walls, whether this be informative material such as notice boards, presentational objects such as paintings or merchandise, architectonic structures or the surface of the wall itself. Wall lighting can, however, also be aimed solely at presenting the wall in its capacity as the surface delineating the room; finally, wall illumination can be a means of indirect general lighting for a room.
Observation

Walls can be lit using point-form or linear luminaires. Wallwasher spotlights offer flexible adjustment for different wall heights. Wallwashers are characterised by the even progression of brightness along the wall. Lens wallwashers have special lens reflector systems. Washlights project the light evenly onto the wall surface, while maintaining the downlight effect on the room. Linear light sources for wallwashing with fluorescent lamps brighten the wall with perfect uniformity. Using a Softec lens achieves an extremely even illumination of the whole wall even in the higher area right up to the ceiling. Perimeter illumination out of a haunch is positioned directly on the wall. It produces a grazing light effect emphasising the surface texture. The evenness of the wallwashing is only secondary here.

Point-form light sources
Wallwasher spotlights

Point-form light sources
Washlights

Point-form light sources
Lens wallwashers

Linear light sources
Wallwashers
Vertical illumination emphasises the wall faces in terms of their physical make-up. The room is made to look bigger by brightening its walls and ceiling etc. Point light sources make the wall surface much more vivid, whereas with linear luminaires a higher uniformity is achieved.

Lighting criteria for walls:
- uniformity of the lighting
- the choice of lamp determines the light colour and colour rendition
Arrangement

The offset from the wall should be at least one third of the room height. Alternatively, the offset from the wall is where a 20 degree line projected from the base of the wall intersects the ceiling. An optimum evenness is obtained when the luminaire spacing is the same as the offset from the wall. Wallwashers only develop their optimal evenness as of a minimum number of three luminaires. The position of a wallwasher in a room corner should lie on the 45° line.

Applications

Washlighting illumination for vertical surfaces of:
- museums
- exhibitions
- trade-fair stands
- sales and representational areas

Preferred luminaire groups
- wallwashers
- washlights
- lens wallwashers
- double washlights
- perimeter luminaires

Projects:
British Museum, London
Crescent House, Wiltshire
Museum Punta della Dogana, Venice
Weimar College of Music
In high rooms the luminaires are beyond the direct field of vision. As the room height increases the brightness of the wall decreases, if the lighting remains constant. Wallwashers are characterised by the even progression of brightness along the wall. Lens wallwashers have special lens reflector systems. Linear light sources for wallwashing with fluorescent lamps provides a perfectly uniform brightening of the room. Using a Softec lens, an extremely even illumination of the whole wall can be achieved even in the higher area right up to the ceiling. The perimeter illumination out of a haunch is positioned directly on the wall. It produces a grazing light effect and emphasises the surface texture. The evenness of the wallwashing is secondary.
Conclusion

Vertical illumination emphasises the walls – or other room limits – in terms of their physical make-up. The room is made to look bigger by brightening the wall faces. Point-form light sources make the wall surface much more vivid while with linear luminaires a higher uniformity is achieved. As the room height increases the distance of the luminaire to the wall must be increased. The reduction of the mean illuminance in higher rooms can be compensated for by having a higher lamp power and by increasing the number of luminaires. Wallwashing only produces an even brightness on matt surfaces.

Lighting criteria for high walls
- uniformity of the lighting
- the choice of lamp determines the light colour and colour rendition
Arrangement

Whereas for normal room heights the luminaire spacing is the same as the offset from the wall, in higher rooms it must be reduced to compensate for the otherwise sinking illuminance. The offset from the wall is where a 20 degree line projected from the base of the wall intersects the ceiling. The position of a wallwasher at the end of the wall should lie on the 45 degree line.

Applications

Washlighting illumination for vertical surfaces in:
- museums
- exhibitions
- trade-fair stands
- sales and representational areas

Preferred luminaire groups
- wallwasher
- washlights
- lens wallwashers
- perimeter luminaires

Projects:
Heart of Jesus Church, Munich
Bank of China, Beijing
BMW factory, Leipzig
Martin-Gropius building, Berlin
Observation

Point-form wallwashers make surface textures clearly visible. When using linear light sources the wall face appears even and the surface texture is only emphasised to a limited extent. When using perimeter luminaires mounted directly on the wall, there is no evenness and great vividness is created.
Conclusion

Linear light sources at a short offset from the wall most vividly enhance the surface texture. Conversely, point-form light sources at a short offset from the wall produce their own light pattern that, admittedly, does accentuate the texture, but does not permit an even wallwashing. Grazing light on walls can accentuate any surface irregularities.

Applications

The smaller the offset from the wall, the clearer the surface texture is enhanced. When using grazing light, the evenness of the wall illumination is greatly reduced.

Preferred luminaire groups
- wallwashers
- washlights
- lens wallwashers
- perimeter luminaires

Projects:
Bodegas Portia, Gumiel de Izán
Neues Museum (New Museum), Berlin
ABN AMRO, Sydney
Heart of Jesus Church, Munich
With ceiling illumination, either light is shone to illuminate the ceiling in its own right or the ceiling is merely used as a reflector for general lighting. The ceiling is primarily emphasised, when it has an intrinsic communicative value, e.g. due to architectonic structures. Illuminating the ceiling to provide indirect general lighting requires it has a high reflectance. It should be noted the ceiling will then be the brightest surface in the room and will therefore be emphasised.
**Guide**

**Indoor lighting | Lighting applications | Ceiling**

**Ceiling, plan**

**Observation**

The luminaires for washlighting the ceiling can be mounted on the walls or in the ground. As linear luminaires, light structures act as independent architectural elements, whereas ceiling washlights are more secondary to the architecture. Light structures emit diffuse light with low brilliance.

**Light structures**

**Ceiling washlights**

**Conclusion**

The choice of luminaire type is dependent on the ratio of room area to room height. In low rooms with large floor areas an even illumination of the ceiling using light structures presents itself as the best option. Ceiling washlights require a large distance from the ceiling due to their asymmetric light distribution.

**Arrangement**

The prerequisite for ceiling illumination is a sufficiently high room in order to achieve an even distribution of light. Ceiling washlights should be mounted above eye-level. The distance from the ceiling depends on the level of evenness required and should be at least 0.8m.
Applications

Washlighting ceiling illumination for
- offices
- historical buildings
- churches
- theatres
- passages

Preferred luminaire groups
- ceiling washlights
- uplights
- light structures

Projects:
Weimar College of Music
Shanghai Museum
Ezeiza Airport, Buenos Aires
Observation

Luminaires for lighting support structures can be mounted on the structure itself, on the walls or in the floor. A washlighting illumination adds emphasis to the whole ceiling surface. Narrow-beamed luminaires accentuate the support structure in particular.

Light structures

Light structures with ceiling washlights

Ceiling washlights

Spotlights
Conclusion

The selection of the type of luminaire is dependent on the scale and the proportion of the support structure. Spotlights can also be attached directly to components of the support structure. The arrangement of the luminaires should be oriented around the design of the support structure. Ceiling washlights, due to their asymmetric light distribution, require a larger offset from the ceiling.

Applications

Indirect ceiling lighting for
- historical buildings
- churches
- theatres
- passages

Preferred luminaire groups
- spotlights
- light structures
- ceiling washlights

Project:
Palacio de la Aljaferia, Zaragoza
**Observation**

For floor lighting, either wash-lighting is applied to the floor surface alone or the room as a whole is illuminated with downlights with direct light from above. Floor washlights particularly highlight the floor surface and its physical make-up.

**Downlights**

Due to their asymmetric light distribution, floor washlights provide grazing light illumination of the floor. They ensure a high degree of visual comfort thanks to their low mounting height. The elimination of glare from downlights is determined by the cut-off angle. The evenness of the downlight lighting is higher.

**Floor washlights**
Floor

Applications

Floor washlighting for
- walkways and foyers in hotels, theatres, cinemas and concert halls
- hallways
- steps and stairs

Preferred luminaire groups:
- downlights
- floodlights

Projects:
Lamy Innovation Workshop, Heidelberg
Konrad Adenauer Fund, Berlin
Objects can be accentuated with great effect to turn them into real eye-catchers. Visual impressions can be given an unusual appearance by selecting a crisp edged illumination. The opposite of such dramatic lighting is a uniform, large area lighting solution.
Observation

Objects in the room or area can be illuminated flexibly using track-mounted spotlights or floodlights. When illuminating an object with one spotlight in the direction of vision, the modelling effect is weak. Two spotlights, with sculpture accessories, shining from different directions create a balanced, three-dimensional effect. The brightness contrasts are milder compared to when using just one spotlight. Illuminating from below produces interesting effects since the light is coming from an angle which is unusual for the observer.

Spotlight, front elevation

Spotlight, side elevation

Spotlight, isometric

Spotlight, underside
Floodlights

Narrow beam spotlights accentuate the object while floodlights show the object in the context of its surroundings. This reduces the modelling effect. Lighting from below can have the effect of making things look very strange. The possibility of dazzle must be prevented here in particular.

Conclusion

Arrangement

Objects in the room can be illuminated with an angle of incidence of 30° to 45° to the vertical. The steeper the incident light, the stronger the shadows. When the angle of incidence is 30°, strong reflection or undesirable shadows on people and objects are avoided.

Applications

Accent lighting for
- museums
- exhibitions
- trade-fair stands
- sales and representational areas

Preferred luminaire groups
- spotlights
- floodlights

Projects:
Passeig de Gràcia, Barcelona
Museum of Contemporary Art, Helsinki
Guggenheim Museum, Bilbao
Hermitage, Saint Petersburg
Object on the wall

Observation

Objects on the wall can be flexibly illuminated with track-mounted spotlights or floodlights. Spotlights highlight the wall-mounted picture and create a decorative effect. Individual wallwashers accentuate the picture more discretely than spotlights. Several wallwashers illuminate the wall evenly. The object is not emphasised. Floodlights provide a homogenous illumination of the entire wall surface. A contour spotlight ensures very strong, effective emphasis of the wall-mounted picture.

Spotlights

Wallwasher spotlights

Floodlights

Contour spotlights
Conclusion
Narrow beam spotlights accentuate the object while floodlights show the object in the context of its surroundings. Contour spotlights can illuminate the object with a crisp focused beam and thus highlight particularly well. This can result in an effect that makes the object look strange because the object itself seems to emit light.

Arrangement
Objects on the wall can be illuminated with an angle of incidence of 30° to 45° to the vertical. The steeper the incident light, the more vivid the object appears. On reflective surfaces, e.g. artworks behind glass or oil paintings, care must be taken that the angle of incidence does not cause secondary glare in the observer’s line of vision. In addition, unwanted shadow, e.g. cast by the picture frame onto the picture surface, should also be avoided.

Applications
Accent lighting for
- museums
- exhibitions
- trade-fair stands
- sales and representational areas
Preferred luminaire groups
- spotlights
- wallwashers
- floodlights

Projects:
Museum of Contemporary Art, Barcelona
Museo Deu, El Vendrell
Palacio Real de Madrid
Reichstag, Berlin
Orientation lighting is defined first and foremost by the task of providing orientation. This can be done using luminaires that provide visibility or ones that act as a sign. Floor washlights and wall-mounted downlights provide orientation by illuminating either the floor surface or the room. Orientation luminaires and recessed floor luminaires typically provide orientation by being arranged into lines or by marking out areas.
Conclusion

Low illumination levels are sufficient for orientation purposes. Small luminaires with high luminance clearly set themselves apart from their surroundings.

Applications

Projects:
Light and Building, Frankfurt
Palazzo della Ragione, Bergamo
Canteen, Lüdenscheid
Sevens, Düsseldorf

Orientation lighting for the identification of
- architectural lines
- steps and exclusion zones
- entrances
- routes
- emergency exit routes

Preferred luminaire groups
- floor washlights
- wall-mounted downlights
- recessed floor luminaires
- orientation luminaires
Directive lighting

**Observation**

Directive luminaires provide information or give directions by way of pictograms and inscriptions. Safety and rescue sign luminaires inform on the direction of an escape route or emergency exit.

**Applications**

Application: for identification of:
- exits
- emergency exits, fire exits
- escape and rescue routes

Directive luminaires are often secondary lighting features and should match with the architecture. Luminaires that change colour allow controllable dynamic route markings. Safety and rescue sign luminaires must comply with the regional guidelines.

Preferred luminaire groups
- directive luminaires
- safety sign luminaires
- luminaires for pictograms

**Projects:**
- Palazzo della Ragione, Bergamo
- Deutsches Historisches Museum (German Historical Museum), Berlin
- Norwegian Aviation Museum, Bodo
- Taschenberg-Palais, Dresden
Outdoor lighting concepts can form a continuous whole with the indoor lighting designs. Luminaire groups built to high protection mode form the basis for adding dramatic lighting to architecture, cityscapes and vegetation by night.

Types of lighting  Luminaire groups  Lighting applications

Design examples  Lighting design
The effect of rooms, facades, objects and vegetation greatly depends on the type of lighting. This ranges from general lighting through to specific highlighting. Washlighting forms the background for accent lighting for emphasising objects. In terms of orientation lighting, points of light or rows of lights are used to provide orientation in the outdoor area.
Ambient lighting produced by wide beam light distribution facilitates perception and orientation in the horizontal plane. It contributes to recognising pathways and to save circulation.
Direct and aimed general lighting produces an even illumination on the horizontal working plane. The architecture is visible and it is possible to orientate oneself in the room.

The directed light produces good modelling and brilliance. The uniformity on the working plane increases as the mounting height increases or as the beam angle widens. Directed light enables good appreciation of form and surface texture. The visual comfort increases as the cut-off angle increases. A feature of direct illumination is its highly efficient use of energy.

Downlights cater for an even light distribution on the horizontal plane. They have an inconspicuous design and can be integrated well into the architecture.

Direct, directed general lighting for:
- entrance areas
- arcades
- passages
- atria

Preferred luminaire group
- downlights

Projects:
- Repsol petrol station, Spain
- Congress Palace, Valencia
- Federal Chancellery, Berlin
- Coal washery, Zollverein colliery, Essen
Direct, diffuse general lighting designates an even illumination with respect to a horizontal working plane. The architecture is visible and it is possible to orientate oneself in the room.

Direct, diffuse light produces a soft illumination with little shadow and reflection. The limited formation of shadow results in weak modelling capabilities. Shapes and surface textures are only slightly emphasised. One feature of using fluorescent lamps for the general lighting is an efficient use of energy.

Direct, diffuse general lighting for
- entrance areas
- overhanging or cantilevered roofs
- floor lighting on access driveways, paths and public squares

Preferred luminaire groups
- downlights
- wall-mounted downlights

Projects:
Private residence, Ravensburg
Private residence, Ravensburg
Bodegas Vega Sicilia Wine Cellar, Valladolid
Washlighting illuminates larger objects or spatial zones using wide beam light distribution. In contrast to accent light, it conveys a wide impression. Washlighting enables safe movement on pathways and effectively highlights large objects and areas.

The directed light produces good modelling abilities and enables good appreciation of form and surface structure. Washlighting illumination can serve as a background for accent lighting.

Washlighting illumination for:
- wall lighting
- facades
- entrance areas
- cantilever roofs
- trees
- park and garden complexes
- sculptures
- objects

Preferred luminaire group
- floodlights

Applications

Projects:
Private residence, Southern Highlands, Australia
ERCO Lightpark, Lüdenscheid
Church, Rörvik
Monastery ruins, Paulinzella
Wallwashing

Vertical illuminance defines and structures spatial situations. It makes a significant contribution to the impression of brightness in a space and to a feeling of security.

Uniform wallwashing

Uniform vertical illuminance defines the spatial environment. A uniform brightness distribution from upper edge to floor emphasises walls and façades as a whole. This type of lighting with highly uniform wallwashing is ideal for the illumination of façades, open places, entrances and hedges to facilitate orientation and structure outdoor areas.

Wallwashing with focal emphasis

Wallwashing with focal emphasis complements the uniform wallwashing by adding a highlight in the lower third of the illuminated wall. This type of lighting is ideal to emphasise the lower section of the façade.
Grazing light wallwashing

Grazing light emphasises the material and surface texture of walls and façades. Positioning the luminaire close to the wall produces a graduation of brightness on the vertical axis. Grazing light impressively brings out the texture of natural stone or wood.

Applications

Washlighting illumination for
- facades
- entrance areas
- passages
- atria
- cantilever roofs
- park and garden complexes

Preferred luminaire groups
- floodlights
- washlights
- wallwashers
- recessed floor luminaires

Projects:
Regional government of Lower Saxony and Schleswig-Holstein in Berlin
Kaufhof media façade, Hamburg
Museo del Teatro de Caesar-augusta, Zaragoza
Porches de la Boquería, Barcelona
Accent lighting enables good appreciation of form and surface structure. The focused light produces pronounced shadows and good modelling ability, as well as brilliance. A narrow beam and a high brightness contrast to the surroundings give the object particular emphasis.

**Observation**

Accent light emphasises vegetation, individual objects or architectural elements using narrow beams of light. Bright points in dark surroundings attract attention. They separate the important from the unimportant, allowing individual objects to come to the fore.

**Projectors**

**Directional downlights**

**Conclusion**

Accent lighting enables good appreciation of form and surface structure. The focused light produces pronounced shadows and good modelling ability, as well as brilliance. A narrow beam and a high brightness contrast to the surroundings give the object particular emphasis.
Accent lighting creates points of interest. Structures and textures of objects are clearly emphasised by the directed light.

Accent lighting for:
- facades
- entrance areas
- arcades
- park and garden complexes
- objects

Preferred luminaire groups
- projectors
- directional downlights

Projects:
ERCO Lightpark, Lüdenscheid
ERCO, Lüdenscheid
Sri Senpaga Vinayagar Temple, Singapore
Tommy Hilfiger, Düsseldorf
Orientation lighting improves the perception by adding light points and lines, e.g. along pathways and on stairs. The light must function as a signal. Illuminating the surroundings is of secondary importance here.
Low illumination levels are sufficient for orientation purposes. Small luminaires with high luminance clearly set themselves apart from their surroundings.

Applications
Orientation lighting for the identification of
- architectural lines
- steps and exclusion zones
- entrances
- routes
- emergency exit routes

Preferred luminaire groups
- floor washlights
- wall-mounted downlights
- recessed floor luminaires
- orientation luminaires

Projects:
Sevens department store, Düsseldorf
Hilton Hotel, Dubai
Czartoryski Square, Krakow
Private residence, Palamos
E

Luminaires are available in a wide variety of types, each intended to fulfill different lighting requirements. For external applications it is primarily permanently mounted luminaires that are used.

Projectors  Floodlights  Wallwasher

Façade luminaires  Bollard luminaires  Recessed luminaires

Surface-mounted luminaires  Recessed floor luminaires  Orientation luminaires
Projectors illuminate a narrowly constrained area. The type of mounting and the orientation are variable. Projectors are offered with different beam emission angles and light distributions.

Criteria for projectors:
- choice of lamp determines light colour, brilliance, functional life, light intensity
- emission angle determines the beam of light and is defined by the reflector and the lamp
- cut-off angle limits glare and increases visual comfort
- rotatable and tiltable

Projectors have narrow-beam light distribution with a rotationally symmetrical beam.

The use of accessories is also typical for projectors:
- lenses: spread lenses or sculpture lenses
- filter: colour filter, UV or IR filter
- glare control: anti-dazzle screen

Applications:

Accent lighting for:
- façades
- entrance areas
- arcades
- park and garden complexes
- objects

Projects:
Norwegian Aviation Museum, Bodo
ERCO Lightpark, Lüdenscheid
ERCO Lightpark, Lüdenscheid
ERCO, Lüdenscheid
Floodlights have a wide-beam characteristic. They are offered with an axially symmetrical or asymmetrical light distribution.

Criteria for floodlights
- choice of lamp determines light colour, functional life, efficiency, light intensity
- uniformity: optimised reflector for even illumination of areas

Floodlights with axially symmetrical light distribution provide even illumination of objects or areas. Light distribution with focal emphasis.

Applications
Washlighting provides an even illumination for:
- wall lighting
- façades
- entrance areas
- overhanging or cantilevered roofs
- park and garden complexes
- sculptures
- objects

Surface-mounted luminaires act as features themselves. Their arrangement should match their surroundings.

Projects:
Private residence, Southern Highlands, Australia
ERCO Lightpark, Lüdenscheid
Centenary Hall, Bochum
Sri Senpaga Vinyagar Temple, Singapore
Wallwashers have a wide-beam characteristic. They are offered with an asymmetric light distribution.

Criteria for wallwashers:
- choice of lamp determines light colour, functional life, efficiency, light intensity
- uniformity: optimised reflector for even illumination of areas
- gradient: soft edges to the beam of light

Wallwashers
Recessed-mounted wallwashers with asymmetric light distribution provide an even illumination of areas.

Wallwasher, tiltable
Recessed-mounted wallwashers with asymmetric light distribution provide an even illumination of areas. Surface-mounted downlights can be mounted on walls, ceilings or floors and in addition can also be tilted.

Applications
Wallwashing is an important component of architectural lighting for adding emphasis to façades. Further applications are:
- entrance areas
- passages
- atria
- overhanging or cantilevered roofs
- park and garden complexes

As recessed luminaires, wallwashers are inconspicuous architectural details. Surface-mounted downlights act as a room feature. They should correspond to the architecture in their arrangement and form.

Projects:
Regional government of Lower Saxony and Schleswig-Holstein, Berlin
Kauhfom Media Facade, Hamburg
ERCO P1, Lüdenscheid
Concentration Camp memorial, Belzec
Ceiling and wall-mounted downlights are defined first and foremost by their type of mounting and not by their light characteristics. They are available with narrow-beam, wide-beam, symmetrical or asymmetric light distribution. Some luminaires can be positioned either on the wall or on the ceiling.

Criteria for ceiling and wall-mounted downlights:
- choice of lamp determines light colour, functional life, efficiency, light intensity
- uniformity: optimised reflector for even illumination of areas

Façade luminaires
Façade luminaires are offered with narrow-beam, wide-beam, symmetrical or asymmetric light distribution. The light can be distributed either via a single-sided or double-sided light aperture.

Wall-mounted downlights
Wall-mounted downlights, with their diffuse beam in the room, provide good visual comfort. They can also be mounted on the ceiling.

Wall-mounted downlights, shielded
Wall-mounted downlights with half-shielded face offer good visual comfort and illuminate the floor area in particular.
Applications

Projects:
Private residence, Ravensburg
Private residence, Ravensburg
Zara, Munich
Cultural Centre and Coastal Museum NORVEG, Rörvik

For illumination of:
- façades
- entrance areas
- overhanging or cantilevered roofs
- floor lighting on access drive-ways, paths and public squares

The position and design of the ceiling and wall-mounted down-lights should be chosen to match the with the architecture. Façade luminaires should be arranged such that the elements to be illuminated are optimally lit and no light shines past the objects.
Bollard luminaires have a wide-beam characteristic. They are offered with an asymmetric light distribution.

Criteria for luminaires for open area and pathway lighting:
- choice of lamp determines light colour, functional life, efficiency, light intensity
- uniformity: optimised reflector for even illumination of areas
- gradient: soft edges to beam of light
- cut-off angle increases visual comfort and limits glare and light pollution
- light output ratio is increased by optimised reflector technology

**Luminares for pathway lighting**
Pathway lighting luminaires with asymmetric light distribution provide uniform illumination on pathways. The light is spread in its width so that pathways can be evenly illuminated. Their small shape makes these luminaires suitable for lighting steps.

**Luminares for open area lighting**
Light for illuminating open spaces is generated by an asymmetric reflector-flood system. A sculpture lens acting as safety glass directs the light deep into the outdoor area.

**Facade washlights**
Floor washlights with asymmetric light distribution provide an even illumination of buildings.
Applications

Projects:
Panticosa resort, Panticosa
Private residence, Berlin
ERCO, Lüdenscheid
Art hall, Emden

Bollard luminaires are mainly used for illuminating the following:
- façades
- entrance areas
- arcades
- passages
- floor lighting on access driveways, paths and public squares
- orientation lighting on pathways, drives, entrances and steps
- park and garden complexes

As recessed luminaires, these are inconspicuous architectural details. Free-standing luminaires act as features in the room. Their arrangement should correspond to the surroundings.
Light

Recessed luminaires emit a beam that is directed downwards at either a perfectly vertical or an adjustable angle. They are usually mounted on the ceiling and illuminate the floor or walls. They are offered with narrow-beam, wide-beam, symmetrical or asymmetrical light distribution. The cut-off angle of narrow-beam downlights means they are largely free of glare. On downlights with Darklight reflector, the lamp’s cut-off angle is identical to that of the luminaire. This gives a luminaire with the widest beam possible while simultaneously having an optimised light output ratio. The use of a diffuser reduces the luminance in the luminaire and thereby improves the visual comfort and the evenness.

Downlights
Downlights have a rotationally symmetric beam that is directed vertically downwards.

Wallwashers
Wallwashers have an asymmetrical light distribution that is directed onto vertical surfaces. They provide even illumination for wall or façade surfaces. Special lens systems for lens wallwashers ensure even wall illumination. The light is spread out by the lens and directed onto the wall by wallwasher reflectors. The Darklight reflectors of lens wallwashers are visible from below and are glare-free.

Directional luminaires
Directional luminaires provide highlighting for individual areas or objects with a medium to narrow light distribution.

Criteria for recessed luminaires
- choice of lamp determines light colour, functional life, efficiency, light intensity
- emission angle determines the beam of light and is defined by the reflector and the lamp
- cut-off angle limits glare and increases visual comfort
- light output ratio is increased by optimised reflector technology
Arrangement

The offset from wall should measure approximately half of the luminaire spacing in order to achieve sufficient brightness on the wall and well proportioned scallops of light. To attain an even illumination on a reference plane, the luminaire spacing should not exceed the mounting height \( h \) by more than 1.5:1. An optimal evenness is achieved when \( a=\frac{h}{2} \).

Applications

Downlights provide general lighting for
- entrance areas
- arcades
- passages
- atria

Recessed downlights are inconspicuous architectural details, whereas surface-mounted downlights and pendant luminaires act as room features. They should correspond to the architecture in their arrangement and design.

Projects:
Repsol petrol station, Spain
Congress Palace, Valencia
Federal Chancellery, Berlin
Intercontinental Resort, Berchtesgaden
Surface-mounted luminaires emit a beam that is directed downwards or to the side. They are usually mounted on the ceiling and illuminate the floor or walls. Surface-mounted luminaires are offered with narrow-beam, wide-beam, symmetrical or asymmetrical light distribution. The cut-off angle of narrow-beam downlights means they are largely free of glare. On downlights with Dark-light reflector, the lamp’s cut-off angle is identical to that of the luminaire. This gives a luminaire with the widest beam possible while simultaneously having an optimised light output ratio. The use of a diffuser reduces the luminance in the luminaire and thereby improves the visual comfort and the evenness.

Criteria for surface-mounted luminaires:
- choice of lamp determines light colour, functional life, efficiency, light intensity
- emission angle determines the beam of light and is defined by the reflector
- cut-off angle limits glare and increases visual comfort
- light output ratio is increased by optimised reflector technology

Downlights
Downlights have a rotationally symmetrical beam that is directed vertically downwards.

Wallwashers
Surface-mounted wallwashers with asymmetrical light distribution provide an even illumination of areas.

Directional downlights
Directional downlights provide highlighting for individual areas or objects with a medium to narrow light distribution.
Recessed floor luminaires emit their beam upwards. They are offered with narrow-beamed, wide-beamed, symmetric or asymmetric light distribution.

Criteria for recessed floor luminaires:
- choice of lamp determines light colour, functional life, efficiency, light intensity
- uniformity with wallwashers: optimised reflector for even illumination of areas
- range of tilt for directional luminaires with high glare protection

**Light**

**Uplights**
Uplights feature an upwards directed beam with symmetrical light distribution. The narrow, rotationally symmetrical beam is used for highlighting objects.

**Lens wallwashers**
Lens wallwashers feature an upwards directed beam with asymmetrical light distribution. They provide an even illumination of walls.

**Directional uplights**
Directional luminaires provide highlighting for individual areas or objects with a medium to narrow light distribution. The beam can be titled.

**Uplight, diffuse**
Recessed floor luminaires with diffuse light intensity distribution are used for marking paths or emphasising architectural lines.
Applications

Accent lighting or floodlighting for:
- facades
- entrance areas
- arcades
- passages
- atria
- overhanging or cantilevered roofs
- park and garden complexes

Recessed floor luminaires are inconspicuous architectural details. They should correspond to the architecture in their arrangement and form.

Projects:
Glass pavilion, Glass technical college, Rheinbach
Brandenburg Gate, Berlin
Khalil Al-Sayegh, Dubai
Benrath Castle, Düsseldorf
Orientation luminaires are defined first and foremost by the task of providing orientation. This can be achieved by luminaires that function as sources of illumination or as signals.

Criteria for orientation luminaires:
- Luminance: noticability of the luminaires in their surroundings.

Orientation luminaires
Orientation luminaires with point-form front lens act as a local orientation light.

Floor washlights
Floor washlights form points of light on the wall and serves as an orientation light on the floor surface.
Guide
Outdoor lighting | Luminaire groups
Orientation luminaires

Applications

Projects:
- Sevens department store, Düsseldorf
- Hilton Hotel, Dubai
- Czartoryski Square, Krakow
- Private residence, Palamos

For identifying:
- architectural lines
- steps or restricted areas
- entrances
- routes
- emergency exit routes
Illuminating facades by night changes the atmosphere of a city. In urban areas or civic parks, points of interest can be created to enable orientation and to establish spatial reference points. Light in the outdoors also extends one’s perception when looking outside from with a building.
Wall and facade lighting at night extends one’s perception and defines spatial limits. Vertical illumination is significant in the visual surroundings for identifying areas in terms of their form, regardless of whether they are facades or walls covered with climbing plants. The objective may be to obtain a uniform wallwashing comparable to that in the indoor area, or to gently illuminate a building against the nocturnal environment. The arrangement of the luminaires is dependent on the desired uniformity and illuminance. In the outdoor area at night, a low brightness is often sufficient for making objects visible and for making contrasts.
Wallwashers are noted for giving an even progression of brightness on the wall.

Vertical illumination emphasises the surfaces delineating the room in terms of their physical makeup. The room is made to look bigger by brightening the wall faces. Point-form light sources make the wall surface much more vivid. Wallwashing only achieves a uniform brightness on matt surfaces.

**Lighting criteria for walls:**
- uniformity of the lighting
- the choice of lamp determines the light colour and colour rendition
Arrangement

The offset from the wall should be at least one third of the wall height. Alternatively, the light’s angle of incident should be 20° to the vertical. An optimum evenness is obtained when the luminaire spacing is the same as the offset from the wall, or at least does not exceed it by more than 1.5 times. Wallwashers only develop their optimal evenness as of a minimum number of three luminaires.

Applications

Washlighting illumination for vertical surfaces of:
- wall lighting
- facades
- entrance areas

Preferred luminaire groups
- wallwashers

Projects:
ERCO, Lüdenscheid
Benrath Castle, Düsseldorf
Berliner Tor Center, Hamburg
Concentration Camp memorial, Belzec
Given the same lighting, as the wall height increases the brightness of the wall decreases. Wallwashers are characterised by the even progression of brightness along the wall. Lens wallwashers have special lens reflector systems.

Vertical illumination emphasises the wall faces in terms of their physical makeup. The room is made to look bigger by brightening its walls and ceiling. Directed light makes the wall surface much more vivid. As the wall height increases the distance of the luminaire to the wall must be increased. The reduction of the mean illuminance on the wall can be compensated for by having a higher lamp power and by increasing the number of luminaires.

**Conclusion**

Lighting criteria for high walls:
- uniformity of lighting
- the choice of lamp determines the light colour and colour rendition
Whereas for normal wall heights the luminaire spacing is the same as the offset from the wall, for higher walls it must be reduced to compensate for the otherwise sinking illuminance. The offset from the wall is given where a 20° line projected down from the top of the wall meets the ground.

Applications

Washlighting illumination for vertical surfaces of:
- wall lighting
- facades
- entrance areas

Preferred luminaire groups
- wallwashers
- lens wallwashers

Projects:
Regional government of Lower Saxony and Schleswig-Holstein in Berlin
Georg Schäfer Museum, Schweinfurt
Brandenburg Gate, Berlin
Sacred Heart church, Munich
**Observation**

Point-form light sources at a short offset from the wall produce their own light pattern that, admittedly, does accentuate the texture, but does not permit an even wallwashing. Grazing light on walls can emphasise any surface irregularities.

**Downlights**

![Downlights Image]

**Wallwashers**

![Wallwashers Image]

**Lens wallwashers**

![Lens Wallwashers Image]

**Directional luminaires**

![Directional Luminaires Image]

**Conclusion**

Directed grazing light makes surface textures clearly visible.
Applications

Projects:
Röhrmeisterei restaurant, Schwerte
Sri Senpaga Vinayagar Temple
Private residence, Germany
Museu Etnològic, Barcelona

The smaller the offset from the wall, the clearer the surface texture is enhanced. When using grazing light, the evenness of the wall illumination is greatly reduced.

Preferred luminaire groups
- downlights, narrow-beamed
- wallwasher
- recessed floor luminaires
  (uplights, lens wallwashers, directional luminaires)
With ceiling illumination, either light is shone to illuminate the ceiling in its own right or the ceiling is merely used as a reflector for general lighting. The ceiling is primarily emphasised, when it has an intrinsic communicative value, e.g. due to architectonic structures.
Guide
Outdoor lighting | Lighting applications | Ceiling

Ceiling, plan

Observation
The luminaires for washlighting the ceiling can be mounted on the walls or in the ground.

Uplights

Recessed floor luminaires

Conclusion
Selecting the luminaire type is dependent on the room and its use. For ceiling washlights, a minimum distance to the ceiling is required. To avoid glare, recessed floor spotlights for illuminating ceilings should not be installed in heavily trafficked areas.

Arrangement
The prerequisite for ceiling illumination is a sufficiently high room in order to achieve an even distribution of light. Ceiling washlights should be mounted above eye-level. The distance from the ceiling depends on the level of evenness required and should be at least 0.8m.
Applications

Projects:
- Stansted Airport, London
- Glass pavilion, Glass technical college, Rheinbach
- Jahrhunderthalle, Bochum
- Cosmo petrol station, Tokyo

Washlighting ceiling illumination for:
- entrance areas
- arcades
- passages
- atria
- overhanging or cantilevered roofs

Preferred luminaire groups:
- ceiling washlights
- recessed floor spotlights
Luminaires for lighting support structures can be mounted on the structure itself, on the walls or in the floor. A washlighting illumination adds emphasis to the whole ceiling surface. Narrow-beamed luminaires accentuate the support structure in particular.

Observation

Spotlights

Floodlights

Recessed floor luminaires, directional luminaires
Conclusion

The selection of the type of luminaire is dependent on the scale and the proportion of the support structure. Spotlights can also be attached directly to components of the support structure. The complete support structure can be illuminated with floodlights. To avoid glare, recessed floor spotlights for lighting the support structure should not be installed in heavily trafficked areas. The arrangement of the luminaires should be oriented around the design of the support structure.

Applications

Ceiling lighting for:
- entrance areas
- arcades
- passages
- atria
- overhanging or cantilevered roofs

Preferred luminaire groups
- spotlights
- ceiling washlights
- recessed floor luminaires

Projects:
Post-Tower, Bonn
Ciudad de las Artes y las Ciencias, Valencia
Jahrhunderthalle, Bochum
Museo del Teatro de Caesar-augusta, Zaragoza
When floor lighting, the floor surface can be illuminated with direct light from downlights or from floodlights positioned on the sides. Floor washlights particularly emphasise the floor surface and its physical make-up.

Observation

Pathway luminaires

Luminaires for open-area lighting

Downlights

Downlights, narrow-beamed
Conclusion

Due to their asymmetric light distribution, floor washlights provide grazing light illumination of the floor. They ensure a high degree of visual comfort thanks to their low mounting height. A soft beam gradient reduces the contrast with the surroundings. The elimination of glare from downlights is determined by the cut-off angle.

Applications

Projects:
ERCO, Lüdenscheid
Eberbach monastery, Eltville
Private residence, Berlin
Private residence, Palamos

Floor washlighting for:
- driveways
- pathways
- public squares

Preferred luminaire groups:
- downlights
- floor washlights
- bollard luminaires
- mast luminaires
Objects can be accentuated with great effect to turn them into real eye-catchers. The appearance of objects can be made to look unusual by selecting a strong grazing light. The opposite of such dramatic lighting is a uniform, large area lighting solution.
Objects in the room or area can be illuminated with spotlights or floodlights. When illuminating an object head-on with one spotlight in the direction of vision, the modelling effect is weak. Two spotlights, with sculpture accessories, shining from different directions create a balanced, three-dimensional effect. The brightness contrasts are milder compared to when using just one spotlight. Illuminating from below produces an interesting but mysterious effect since the light is coming from an angle which is unusual for the observer.
Conclusion

Narrow-beam spotlights place emphasis on the object alone, whereas floodlights show the object in the context of its surroundings. This reduces the modelling effect. Lighting from below can have the effect of making things look very strange.

Arrangement

Objects in the room can be illuminated with an angle of incidence of 30° to 45° to the vertical. The steeper the incident light, the stronger the shadows.

Applications

Accent lighting for
- park and garden complexes
- sculptures

Preferred luminaire groups
- spotlight
- floodlights

Projects:
Norwegian Aviation Museum, Bodo
ERCO, Lüdenscheid
Rhenish State Museum, Bonn
Let The Dance Begin, Strabane
Objects on the wall can be illuminated with spotlights or floodlights. Spotlights highlight the object and create a decorative effect. Due to their even illumination of the complete wall surface, floodlights accentuate the object less than spotlights.

**Observation**

**Spotlights**

**Floodlight from above**

**Floodlight from below**

**Recessed floor and directional luminaire**

**Lens wallwashers**
**Conclusion**

Narrow-beam spotlights accentuate the object while floodlights show the object in the context of its surroundings.

**Arrangement**

Objects on the wall can be illuminated with an angle of incidence of 30° to 45° to the vertical. The steeper the incident light, the more three-dimensional the object appears.

**Applications**

Accent lighting for
- facades
- entrance areas
- park and garden complexes
- sculptures

Preferred luminaire groups
- spotlight
- wallwashers
- uplights

**Projects:**
- ERCO, Lüdenscheid
- Vietnam Veterans Memorial, Washington DC
- Sinnet Tennis Club, Warsaw
The form of facades is determined not only by their material and shape but also by the light and its direction and colour. The appearance of a facade alters during the course of the day due to the changing direction of light and the varying components of diffuse and direct light. Different light distributions and the use of lighting control systems give facades an appearance of their own at night. Varying illuminances differentiate components or areas of a facade. Grazing light emphasises facade details. Washing facades allows them to appear in their entirety. Shining any light beyond the facade surfaces, either to the sides or over the top, should be avoided.
Washlighting creates a very uniform light distribution on the facade. A line of light marks out the edge of the building against the night sky. Uplights rhythmically divide up the facade. Under the light of up-downlights, graphic patterns are produced by the definite beams.
Washlighting facades can make them appear flat. Reducing the illuminance as the facade height increases gives a low-contrast transition to the dark night sky. Grazing light emphasises the surface textures of materials. Progressions of light on untextured walls become the dominating feature and are seen as independent patterns in their own right. Large, uniform surfaces can be given structure with patterns of light. Beams of light that do not match or correspond with the architecture are perceived as disturbing.

The facade lighting can be positioned on the ground, on a mast or on the building. Wallwashers offset from the facade at one third to half the facade height avoid long shadows. Luminaires positioned close to the facade produce grazing light with a strong emphasis on the surface textures and structures. Recessed floor luminaires are architecturally discrete. Overgrown vegetation must be prevented. Mast luminaires will appear as additive features in front of the facade. Cantilever arms allow direct mounting to the building. Shining any light beyond the facade surfaces, either to the sides or over the top, should be avoided.
Solid facade

Projects:
Georg Schäfer Museum, Schweinfurt
ERCO Lightpark, Lüdenscheid
ERCO Lightpark, Lüdenscheid Cultural Centre and Coastal Museum NORVEG, Rörvik
**Observation**

Floodlights produce a uniform illumination on the facade. Washlighting with point-shaped light sources makes the surface texture and structure clearly visible. Accentuating the columns detaches these from the surrounding facade. Uplights positioned on two sides emphasise the volume of the column. Downlights accentuate the column and illuminate the floor area. The combination of uplights and downlights augments the vertical facade division by lighting from above and below.

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<td><strong>Uplights, double-sided layout</strong></td>
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<td><strong>Downlights</strong></td>
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Facade, vertically divided

Downlights and uplights

Narrow beams of light intensify the effect of the vertical division. To avoid shadows at the side, the luminaires should be positioned at right angles, parallel to the facade. Strong contrasts and heavy shadow can be compensated for by washlighting the facade as a form of general lighting. The luminaires should be positioned in a rhythm corresponding to that of the facade divisions.

Conclusion

Applications

Projects:
- Brandenburg Gate, Berlin
- Municipal works, Lüdenscheid
- Ruhr Festival Theatre Congress Centre, Recklinghausen
- Faena Hotel, Buenos Aires
Guide

Outdoor lighting | Lighting applications | Facade

Horizontally divided facade

Observation

Floodlights illuminate the entire facade and emphasise the horizontal divisions by casting heavy shadows. Lines of light echo the horizontal structure on the darker facade surface.

Floodlights

Lines of light

Conclusion

Luminaires positioned close to the facade highly emphasise its three-dimensional nature. Long heavy shadows cast by facade divisions can be reduced by increasing the offset of the luminaire from the facade. The steeper angle of incidence for the light in the upper region of the facade casts longer shadows than in the lower area.

Applications

Projects:
Hong Kong and Shanghai Bank, Hong Kong
Palazzo della Borsa, Triest
Kauhof department store, Mönchengladbach
Facade with projecting or recessed sections

Observation
Wide-beam floodlights set far from the building illuminate the facade evenly. Facades with large protruding sections or insets will feature heavy shadows. Different illuminances or light colours augment the differentiation of the facade. Uplights mark out the internal corners with grazing light.

Floodlights

Spotlights with different illuminances

Spotlights with different light colours

Uplights
Conclusion

Differentiated illuminances, light distributions and light colours add rhythm to the appearance of the facade. Harsh contrasts between accentuated and unlit areas can be compensated for by using washlighting to perform the general lighting. Increasing the luminaire offset from the facade reduces the formation of heavy shadow. The luminaire arrangement should correspond to the pattern of facade division.

Applications

Projects:
Museum of Arts and Crafts, Hamburg
Palacio de la Aljaferia, Zaragoza
Observation

Under daylight conditions the window surfaces appear dark. At night, illuminated interiors provide a strong contrast between the dark facade surface and bright windows. Floodlights produce uniform light distribution over the facade. Illuminating the window embrasure accentuates the frame of the facade opening, whereas narrow-beam uplights emphasise the facade’s grid pattern.
Indoor users should not be dazzled. Luminaires shining into the interior impair the view out of the building. Lighting control systems can be used to control the light in individual rooms and to create patches of light on the facade.
**Guide**

Outdoor lighting | Lighting applications | Facade

**Banded facade**

**Observation**

Under daylight conditions the strip of windows appears dark. Illuminating the indoor areas at night forms a strong contrast between dark facade surfaces and a bright strip of windows. The lighting on the balustrades augments their horizontal structure.

**Daylight**

![Daylight Image]

**Uplights, indoor**

![Uplights, indoor Image]

**Band of light**

![Band of light Image]

**Conclusion**

The strong contrast between bright indoor lighting and the dark outer surface at night can only be compensated for to a small extent with facade wash-lighting.
Applications

Projects:
Municipal works, Lüdenscheid
Astra Administration, Stockholm
E-Werk event halls/SAP SI offices, Berlin
**Observation**

Under daylight conditions, the transparent facade appears dark and reflects its surroundings. Indoor lighting allows the observer to see into the building. Ceiling washlights in the indoor area emphasise the ceiling surfaces and increase the overall impression of interior brightness at night. The facade construction is silhouetted. Lines of light in the ceiling area of the individual floors underline the horizontal building structure. Uplights emphasise the vertical elements of the facade.

**Daylight**

![Daylight Image](image1)

**Downlights, indoor**

![Downlights Image](image2)

**Uplights, indoor**

![Uplights Image](image3)

**Lines of light**

![Lines of light Image](image4)
Conclusion

The visual perspective from the ground makes the lighting effect of the indoor area appear larger with uplights than with downlights. Dazzling the users of the indoor area should be avoided. Luminaires shining into the indoor area will impair the view out of the building.

Applications

Projects:
Office building, Basel
Ruhr Festival Theatre Congress Centre, Recklinghausen
Zürich Insurance, Buenos Aires
Biblioteca Foral de Bizkaia, Bilbao
In the field of landscaping, trees are the most important elements for forming areas. The shape and size of the trunk and tree crown vary depending on the type of tree. The most well-known tree forms are rounded, columnar, spreading and flat-crowned (e.g. a palm). The winter scene is characterised by filigree branches, while in the summer the leaves of the crown thicken to form a voluminous mass. In addition to the shape, the appearance of trees is also characterised by blossom and foliage in the course of the seasons.
Floodlights aimed upwards make the tree crown appear three-dimensional. Two floodlights from the front, yet to the side, illuminate the crown evenly as a voluminous mass, while floodlights mounted at the side add greater emphasis to the three-dimensionality. Floodlights arranged around three sides illuminate the crown evenly from all sides and reduce the three-dimensionality of the tree form. Floodlights in the background create back-lighting and make the tree crown into a silhouette. Uplights at the trunk accentuate the trunk as a linear feature and visually connect the crown to the ground. Depending on the season, light from above will either emphasise the contour of the crown or accentuate the shadows of the branch structure on the ground.
Guide
Outdoor lighting  |  Lighting applications  |  Vegetation
Trees

Floodlight behind

Uplight

Spotlight from above

Conclusion
Luminaires arranged on several sides give an even illumination of the tree, while one or two luminaires create a greater three-dimensional effect. Narrow-beamed uplights are suitable for highlighting any striking, tall tree trunks. The texture of the bark is brought out stronger when lighting from the front. Positioning the luminaires to the side gives rise to a narrow line of light on the trunk. When illuminating a wall behind a tree, the silhouette of the crown and trunk becomes apparent. Spotlights mounted in atria or on facades can cast the contour of the tree and/or branches as a shadow on the ground.
Observation
Tree growth

One or two luminaires accentuate trees of small dimensions. Several floodlights produce an even illumination of large, fully grown trees.

Small tree

Large tree

Conclusion

Tree growth and avoiding glare are two points that must be considered when arranging and aiming the luminaires. On large trees, several luminaires may be necessary to achieve an even illumination and to avoid a distorted perception of light and dark parts. Flexible, directable luminaires with ground spikes can be repositioned and re-directed as the tree grows. Luminaires recessed into the ground blend into the area of landscape better but require more work to reposition however.
Floodlit illumination of the tree crown particularly brings out the beauty of the outermost blossom in the springtime. In the summer, the dense foliage makes the crown appear as a solid mass. Coloured leaves are characteristic for the autumn. In the winter, the lighting effect is reduced to the filigree branch work.

Lamp selection is a factor that influences the colour of light and the colour rendition of the leaves and blossom. Daylight white colours of light emphasise blue-green foliage colours, whereas warm white colours of light accentuate brownish-red leaves.
Applications

Lighting for
- park and garden complexes
- entrance areas
- atria

Preferred luminaire groups
- spotlights
- floodlights
- uplights

Projects:
Ernst-August-Carree, Hannover
ERCO, Lüdenscheid
ERCO, Lüdenscheid
ERCO, Lüdenscheid

Guide
Outdoor lighting | Lighting applications | Vegetation

Trees
Floodlit illumination emphasises the shape of the tree crown as a solid volume. Positioning the luminaires close to the tree underlines with grazing light the texture of the crown and of the trunk. The illumination from below brings out the three-dimensionality of the crown when the foliage is quite open.

Tree form: rounded

Floodlight, front

Floodlight on the right

Floodlights on three sides

Floodlight behind
Types of trees

Uplight

Spotlight from above

Tree form: Weeping

Floodlight in front

Floodlight on the right

Floodlights on three sides
Types of trees

Tree form: columnar

Spotlight in front

Spotlight on the right
Types of trees

- **Spotlights on three sides**
- **Spotlight behind**
- **Uplight**

**Tree form: conical**

- **Floodlight at front**
- **Floodlight on the right**
Guide

Outdoor lighting | Lighting applications | Vegetation

Types of trees

Floodlights on three sides

Floodlight behind

Tree form: palm

Spotlight in front

Spotlight on the right

Spotlights on three sides
Rounded, weeping trees with dense, low hanging foliage that cannot be seen through, lend themselves to floodlit illumination and the luminaires are best positioned outside the area under the tree. On spreading trees with thin, see-through foliage, illuminating from within the area under the tree, using uplights allows the whole tree crown to appear aglitter. Illuminating a tree with grazing light requires a flat incident beam at approximately 15 degrees. Spherical trees require a greater distance between luminaire and crown than columnar trees do here. Narrow-beamed uplights are particularly suitable for lighting high palms.

Conclusion
The desired illuminance must be selected to suit the reflectance of the leaves.
Clusters of trees

Observation

Luminaires

Floodlights located in front illuminate the tree crowns evenly. Floodlights positioned at the sides produce a hard contrast of light and shadow. Luminaires on two sides avoid hard shadows. Uplights at the trunk emphasise the trunk as a vertical linear feature.

Floodlight at front

Floodlights at sides

Uplights
The cluster of trees can be visually differentiated by using different luminaires and differently aimed. Spatial depth is created by adding lighting emphasis in the foreground, middle ground and background. Stronger brightness contrasts support this effect. Narrow-beamed luminaires provide highlighting, while broad-beamed floodlights take on the task of general lighting.

Having several luminaires with high cut-off angles reduces the glare compared to a few broad-beamed luminaires. Narrow-beamed and well-aimed luminaires reduce the superfluous emission of light into the surroundings. The decentralised illumination of trees allows a differentiated lighting of a cluster of trees. Spotlights are suitable for additional highlights. Tree growth and the avoidance of glare are to be considered when positioning and aiming the luminaires.

Lighting for
- park and garden complexes
- entrance areas
- atria

Preferred luminaire groups
- spotlights
- floodlights
- uplights

Projects:
ERCO, Lüdenscheid
ERCO, Lüdenscheid
Bank of China, Beijing
Bank of China, Beijing
Observation

Upwardly directed spotlights emphasise the tree canopy. Floodlights with asymmetric light distribution give homogenous light from base to canopy even on tall and broad rows of trees. Narrow-beamed uplights highlight the tree trunk as a vertical, linear feature.

Tree form: rounded
Floodlight

Tree form: rounded
Uplights

Tree form: columnar
Spotlights

Tree form: columnar
Uplights
Rows of trees

The effectiveness of rows of trees to delineate space depends to a very large extent on the type of tree. Thus, depending on the type of tree, a closely planted row of trees can appear as a ‘wall’ or a ‘colonnade’. Narrow-beamed and well-aimed luminaires reduce the glare and the spill light into the surroundings. The tree growth must be considered when positioning and aiming the luminaires.

Conclusion

Applications

Lighting for
- park and garden complexes
- entrance areas
- pathways

Preferred luminaire groups
- spotlights
- floodlights
- uplights

Projects:
ERCO, Lüdenscheid
Loher Wäldchen park, Lüdenscheid
Tree-lined avenue

Observation

Upwardly directed spotlights emphasise the tree crowns. Floodlights with asymmetric light distribution give homogenous lighting from base to canopy even on extensive avenues of tall trees. Narrow-beamed uplights highlight the tree trunk as a vertical, linear feature.

Tree form: rounded
Floodlights

Tree form: rounded
Uplights

Tree form: columnar
Spotlight

Tree form: columnar
Uplights
The spatial profile of tree-lined avenues depends to a very large extent on the type of tree. Thus, depending on the type of trees, an avenue of narrowly spaced trees can act as a wall and segregate a definite area or can appear as a colonnade. Narrow-beamed and well-aimed luminaires reduce the glare and spill light into the surroundings. The tree growth must be considered when positioning and aiming the luminaires.
Observation

Broad, upwardly directed beams of light emphasise the underside of the tree canopy. Narrow-beamed uplights highlight the tree trunk as a vertical, linear feature.

Tree form: weeping
Uplights, narrow-beam

Tree form: weeping
Uplights, wide-beam

Tree form: columnar
Spotlights

Tree form: columnar
Uplights
Spacing of trees

Tree form: palm
Spotlights

Tree form: palm
Uplights

Conclusion

The tree crowns of narrowly spaced trees combine to take on the effect of a canopy. Having several narrow-beamed luminaires reduces the glare compared to a few broad-beamed luminaires. On pathways and traffic routes, it must be ensured that the luminaires are well shielded to prevent glare.
Guide

Outdoor lighting

Design examples

In this subchapter, application possibilities for outdoor luminaires are shown using design examples. Design variations are presented using simulations.

Entrance area, small
Entrance area, large
Historical facade

Pathway
The entrance area is formed by a negative volume, which is set apart from the outdoor area by a few steps.

**Planning**

**Design 1**
The wallwashers integrated in the ceiling provide a very homogenous illumination of the wall. The luminaires are integrated into the architecture.

**Design 2**
The light intensity distribution of the downlights determines the overall impression of the scene. On the wall, uniform beams of become apparent and become the formative element. The material texture on the back wall is brought out by the light.

**Design 3**
To meet the functional criteria of an entrance, it is sufficient to illuminate the ground. The overall volume of the entrance recedes into the background.
Guide

Outrood lighting | Design examples

Entrance area, small

Arrangement

Design 1
The offset of the wallwashers from the wall measures half the wall height. The luminaire spacing is equal to the offset from the wall.

Design 2
To achieve a decorative lighting effect, the downlights are positioned near to the wall.

Design 3
The floor washlights are located at a height of 60cm in order to avoid glare.
The design draft shows a representational entrance area with a canopy roof projecting out a long way. This is supported by evenly arranged struts. The main task is to reinforce the representational character using the lighting.

**Planning**

**Design 1**
Downlights follow the form of the cantilever roof along the struts. The circles of light made by the beams on the floor emphasise the dynamics of the circular facade. The wall adjoining onto the glass facade is delicately brightened by recessed ceiling wallwashers.

**Design 2**
Light is projected onto the cantilever roof via ceiling washlights. The roof reflects the light onto the floor. The indirect lighting casts evenly diffused light onto the ground. Additional illumination of the wall can be dispensed with since the wall is also given sufficient light by the reflection from the roof. The luminaires appear as independent architectural elements.

**Design 3**
Each strut is highlighted by four surface-mounted downlights. The physical makeup of the struts is emphasised.
**Arrangement**

### Design 2
The ceiling washlights are mounted at two thirds of the strut height.

### Design 3
The offset of the recessed ceiling wallwashers from the wall measures a quarter of the wall height. The surface-mounted downlights are placed in a circular arrangement around the struts at a short distance away.
Historical facades require lighting concepts that are in harmony with the architectural features. For classical facades, the following features are to be given consideration in the lighting concept:
- columns
- porticoes
- friezes
- facade division into three areas: portal and two side wings

In all the examples listed a faint general lighting of the facade is ensured via lens wallwashers. The lighting should not be incident too steeply, since otherwise irritating heavy shadows could be cast in the area of the friezes.

**Situation**

**Planning**

**Design 1**
The columns are silhouetted against the entrance area, which is illuminated by surface-mounted downlights. The three-dimensional impression of the portico is greatly reduced by the columns that now appear almost flat. The front elevation of the building is clearly divided into three because of the emphasis given to the facade’s central section.

**Design 2**
The columns are illuminated with narrow-beam uplights. The tympanum is illuminated separately. The fact that the entrance area is set forward from the facade becomes much more pronounced. The view is attracted to the central section of the building.

**Design 3**
The facade is clearly given a horizontal division by illuminating the frieze. The overall breadth of the facade becomes more significant. The columns were illuminated as in design 2, but with reduced light intensity so as not to overly emphasise the entrance. Overall, this differentiated lighting concept lends the historical facade a most magnificent character.
Arrangement

The starting point of all three design examples is the homogeneous general lighting of the facade with lens wallwashers mounted as recessed floor luminaires. These are arranged in a line at a distance of one third of the building height in front of the right and left sections of the facade.

Design 1
One surface-mounted downlight with a wide light intensity distribution is positioned behind each and every column.

Design 2
The columns are emphasised by narrow-beam uplights arranged circularly around the columns.

Design 3
Directional luminaires for highlighting the frieze are located at a distance of one tenth of the wall height in front of the two side sections of the facade. The spacing between the directional luminaires themselves is relatively small so that an even illumination of the frieze is obtained. Narrow-beam uplights in the semicircle around the four columns add brightness.
Orientation along pathways can be provided either by primary lighting of the path surface or by emphasising certain reference points in the area.

**Situation**

Orientation is provided here on the one hand by linearly arranged points of light from floor washlights and on the other by marking points of interest. In this example, a low illumination of the pathway by floor washlights is sufficient because illuminating the row of trees provides orientation.

**Planning**

**Design 1**

The path surface is well lit with wide-beam floor washlights. The evenly arranged floor washlights guide one’s view. The adjacent trees are silhouetted against the evenly illuminated wall behind them. The spatial limits are emphasised and this gives the viewer an indication about the volume of the area.
**Design 1**
The uplights are arranged to the right and left of the trees. A row of floor washlights runs parallel to this.

**Design 2**
The lens wallwashers for illuminating the wall are recessed in the floor at an offset from the wall of a third of the wall height.
The development in architecture towards transparency transforms buildings at night into effigies shining from the inside out. Light has advanced to become a marketing topic for a number of cities. A sensitive treatment of light in the outdoor area is crucial for achieving a clear view of the night sky.
Introduction

Dark Sky stands for a lighting design in the outdoor area whereby the lighting concentrates on what is actually essential. Any kind of light pollution is avoided and observation of the night sky is enabled. This approach combines a lasting design concept with a luminaire technology tailored to suit. The cooperative teamwork of lighting designers, architects, landscape gardeners, building sponsors, electrical fitters and luminaire manufacturers forms the basis for a successful implementation of the Dark Sky concept.

Light pollution

The term “light pollution” refers to that spill light which, due to its illuminance, its direction or its spectrum, causes interference in the context in question. Spill light and glare reduce the visual comfort and the desired content of information cannot be conveyed. The ecological consequences include the waste of energy and the negative effects on flora and fauna.

Graphic: Artificial Night Sky Brightness in Europe

Luminaires suitable for Dark Sky applications feature precise light control and a defined cut-off for optimum visual comfort. Having no emission of light above the horizontal plane is a decisive criterion for open area and pathway luminaires. A low luminance at the light aperture avoids excessive contrasts in luminance levels in the outdoor area.

The first design task for a Dark Sky concept is to ascertain for what purpose and with what quality the particular areas are to be illuminated. The following is decisive for a lasting lighting concept:
- adequate illuminance
- avoidance of spill light above the horizontal plane
- correct alignment of luminaires
- reduce or switch off the lighting when no longer needed

The luminaires should be arranged such that the elements to be illuminated are optimally lit and no light shines past the objects. This avoids dazzling the observers.

With the Dark Sky concept the lighting control takes on special significance for regulating the intensity and duration of the lighting for individual zones, thus regulating the overall light emission. The lighting control allows switching and dimming for individual areas. Predefined light scenes can be recalled dependent on the time of day and season via time sensors and motion sensors. Function-dependent lighting scenes for the twilight, evening and night can be controlled dependent on sensors.
Lighting control not only enables the lighting to be adjusted to suit the visual requirements but also allows it to shape and interpret the architecture. Light scenes are easily set up using the appropriate software and can be recalled via an interface. The inclusion of light colours and the time dimension opens up a room for scenographic lighting with dynamic effects. Lighting control systems with sensors or time programs also help adjust the power consumption in a room to its usage and thus optimise the economic efficiency of a lighting system.
The atmosphere in a room can be changed by controlling a number of variables. These include basic functions such as switching circuits on and off through to automatically timed colour progressions. Programming the light scenes means that the settings are saved but can be redefined and adjusted to suit changing requirements.
Switching and dimming are two basic functions of a lighting control system that can be used to produce different lighting situations. Luminaires with variable light colours also include a colour setting mode. Features such as cross-fading and dynamic colour progression are crucial for dynamic lighting designs. Lighting changes can be initiated and regulated automatically via time and sensor control.
The easiest situation is to turn the light on and off with a switch or a push-button. For a variety of light scenes different circuits with separate switches are required. Suitably positioned switches result in easier usage. Most lamps produce full light output immediately. High-pressure discharge lamps, however, usually have a run-up time of several minutes and an even longer cooling-down period before re-ignition.
Dimming is the infinitely variable adjustment of the light output of a light source. It enables the creation of different light scenes, increases the visual comfort and optimises the power consumption. Dimming also prolongs the life of incandescent lamps. Thermal radiators such as tungsten halogen lamps are easily dimmed. Fluorescent lamps and LEDs require special dimmable control gear.
Lighting control  |  Controlling the light  |  Functions

Light colour

The light colour of luminaires with variable colours of light can be defined by hue, saturation and brightness. The possible colours depend on the lamp and the lighting technology used. Coloured light can change the atmosphere of a room and highlight individual objects. RGB colour mixing technology controls the individual primary colours red, green and blue to produce the required light colour.
Scene

A scene is a static lighting situation. It defines the state of all lighting components such as luminaires, light ceilings and light objects with their different switch and dimmer settings. The scenes can be saved in lighting control systems. The user can preset complex luminaire settings and conveniently recall them either manually or automatically.
In regard to lighting, cross-fading refers to the transition from one light scene to another. The cross-fading time is the period required for the scene change. It varies between instant change and a transition of several hours. High-contrast scenes with a short cross-fading time generate considerable attention. Subtle transitions with lengthy cross-fading times, on the other hand, are hardly noticeable. The scene change can be initiated by the user, a sensor, or a timer.
Dynamic colour progression refers to the chronology of colour changes. Within a defined total running time, specific colours are triggered at specified times. There are different options available to repeat this progression, including infinite loop and “forward and back.”
A sequence refers to a progression of successive light scenes. The definition of a sequence requires both individual scenes and information on their transition. A sequence can automatically be repeated once completed or, alternatively, end.
A timer allows light scenes to be recalled at predefined times. Time and calendar functions provide great flexibility for the automation of scenographic lighting. Specified start and end times, for example, set the lighting to specific shop-opening times or licensing hours.
Sensors monitor properties such as brightness or motion and allow an automatic adjustment of the lighting to changing ambient conditions. A brightness sensor can be used for daylight-dependent lighting control. Motion sensors register movement in the room and control the light depending on activity to reduce power consumption.
Buildings increasingly use automatic control systems. The lighting is only one component, operation of solar screen equipment, air-conditioning and security systems are others. Special lighting control systems have the advantage that they can be designed to suit the requirements of a lighting design and are less complex than more extensive building control systems.
Lighting control systems

Lighting control systems switch and dim luminaires, set up light scenes and manage them in space and time. The decision to select a specific system depends on the size of the lighting system, the requirements in regard to controllability, user-friendliness and economic considerations. Digital systems that allow luminaires to be addressed individually provide great flexibility. Their user-friendly features include easy programming and operation along with a simple installation process. Lighting control systems can be integrated as a subsystem into a building management system.
1V–10V

Electronic Control Gear (ECG) is controlled by analogue 1V–10V signals. This technology is widely used in low-complexity lighting systems. The dimmer setting is transmitted via a separate control line. The control gear regulates the output of light from the luminaire. Since this type of ECG cannot be addressed, the control circuit for the control line must be carefully planned, because its allocation cannot be changed. The grouping of the luminaires is determined by the circuits in the electrical installation. Any change of use requires a new arrangement of the connection and control lines. Feedback on lamp failure, etc., is not possible with the 1V–10V technology.

DMX

The DMX (Digital Multiplexed) digital control protocol is predominantly used for stage lighting. In architectural lighting, this protocol is used for features such as media facades or stage-like room lighting effects. The data is transmitted via a dedicated 5-core cable at a transfer rate of 250 Kbits/s which can control up to 512 channels. Each luminaire must have a bus address. When using multi-channel devices with colour control and other adjustable features, each function requires a separate address. For a long time, the data transfer was unidirectional and only enabled the control of devices. It did not provide feedback on aspects such as lamp failure. The DMX 512-A version now allows for bidirectional communication.

DALI

Digital Addressable Lighting Interface (DALI) is a control protocol that makes it possible to control luminaires which have DALI control gear individually. The system allows user-friendly light management in architecture and can be integrated as a subsystem into modern building control systems. The two-wire control line with a transfer rate of 1.2 Kbits/s can be run together with the mains supply cable in a 5-core cable. The bidirectional system allows feedback from the luminaires on different aspects such as lamp failure. The DALI protocol limits the number of devices to 64. The standard version stores the settings for a maximum of 16 luminaire groups and 16 light scenes within the control gear. General information on DALI: www.dali-ag.org

The ERCO Light System DALI, saves settings in a central controller with a greater storage capacity. This allows more luminaire groups, light scenes and fading times along with the coding of the control gear memory for other features. The system is compatible with other DALI devices. Light System DALI can provide both economical light management and scenographic lighting.
Building management systems are used to control different building systems such as the heating, solar screening equipment, and the lighting. They are more complex than systems that solely control the lighting and thus are more involved in terms of planning, installation and operation. An established protocol ensures communication between the systems over a flexible network. The control systems form the basis for building automation, to simplify and automate the different functions in a building. The building automation is divided into three levels: the management level for user-friendly visualisation, the automation level for data exchange, and the local level with sensors and actuators. There are no integrated receiving devices in the luminaires (interfaces) for decoding control signals; lighting control is achieved by wiring individual circuits.
KNX
Konnex (KNX), known through the European Installation Bus (EIB), is a standardised digital control system which controls not only the lighting but also other systems such as heating, ventilation and solar screening equipment. KNX is suitable as a network of electronic installations for building automation. Remote monitoring and control make it easy to use. The data is transmitted over a separate 24V control line-twisted pair wire at a rate of 9.6 Kbits/s. The decentralised communication is bidirectional so that the receiver can also provide feedback. Each bus device can transmit independ-

LON
Local Operating Network (LON) is a standardised digital control protocol which controls building systems and is also used in industrial and process automation. Via TCP/IP, LON networks can be combined to form cross-region networks and be remote-controlled. LON is based on intelligent sensors and actuators. The microprocessor of each LON node, called a “neuron”, can be programmed and configured. The data transfer for up to 32,000 nodes is over a twisted pair wire, as a separate control line, at a rate of up to 1.25 Mbit/s.
Lighting systems can be programmed with software to provide great flexibility and allow an adjustment of the lighting to individual requirements. This results in complex lighting systems with sensors and interfaces that often require professional installation and maintenance. Users require simple day-to-day operation that allows them to make changes themselves. Non-standard systems can include a great deal of complexity to cater for special building requirements. Problems or changes, however, may require the support of a professional programmer. So, standardised lighting systems that allow certain parameters to be changed are easier to operate and enable lighting designers or users to make the necessary changes.

The decision on the type of lighting control system and software depends on technical aspects such as the size of the lighting system, its integration with AV technology or building control systems, and the complexity of the installation. Further criteria for the user to consider are ergonomics, flexibility, and maintenance. A simple installation process, rapid familiarisation and easy to use software aid setup and operation.
Guide

Lighting control

Devices

Lighting control systems are composed of different components: sensors register changes in the surroundings, control panels enable light scenes to be recalled or new lighting parameters to be programmed. The output devices translate the control circuit signals into actions. The connection to the computer allows for easy operation of the lighting control system through software, while gateways facilitate the combination of different control systems.
Sensors are measuring devices that register ambient conditions such as brightness or motion. The lighting is adjusted when the lighting control system receives an impulse or a value above or below a predetermined level.

Light sensor

Motion sensor
Light sensor

A light sensor monitors light levels and enables the automatic control of light scenes depending on available daylight. Using a lighting system in combination with changing daylight levels in rooms ensures a controlled illumination, which is useful, for example, in order to maintain minimum values for workplaces or to reduce the radiation exposure on exhibits in museums. A daylight sensor on the roof (external sensor) measures the illuminance of the daylight and controls the lighting inside. If the light sensor is in the room (internal sensor), it measures the total illuminance of the incident daylight and the lighting in the room in order to control the light level depending on the daylight. The first process is referred to as open loop control, the second as closed loop control.

In combination with scene control, light scenes can be controlled depending on the daylight, for example, by using a twilight switch. In the same manner, the sensor control can be used to operate solar screening equipment.

Motion sensor

Motion sensors register movement in the room and can be used, for example, in vacant offices to dim or switch off the light automatically in order to save power. In museums, the lighting on sensitive exhibits can be reduced when there are no visitors. Installed outdoors, motion sensors can reduce power consumption at night as lighting is switched on only when and where required. The switching thresholds must be set to suit the situation.
Simple applications only require a push-button to operate the lighting control system. Control panels with displays are recommended for sophisticated applications and can also be used to program the lighting system. A remote control device allows light scenes to be recalled from anywhere in the room.
Guide

Lighting control | Devices | Control panels

**Push-button**

A push-button closes or opens a circuit to switch a luminaire group or light scene on or off. To use different functions, a system requires several push-buttons. The functions are determined when the lighting control system is installed.

**Switch**

A switch opens and closes a circuit. It locks into position and does not require continuous pressing as does a push-button. A light switch controls the lighting by switching it on or off.

**Remote control**

A remote control is used to control the light separately from wall-mounted control panels. In conference rooms, a remote control is a convenient device to recall different light scenes from anywhere in the room. An infrared remote control requires an IR receiver to recall any functions.

**GUI**

Graphical User Interface (GUI) is the familiar way of interaction with software on computers or control panels based on graphical images. Simple user interfaces prevent users having to learn complex command languages and simplify the operation. A GUI can be combined with a touch screen so that interaction takes place directly on the screen.
Output devices are actuators or controllers that translate the signals in a control circuit into an action. Actuators (e.g. relays) or dimmers operate or control the light output through voltage changes. Controllers have their own processors and send signals to the control gear.
Relay

A relay is a switch that is activated by electric current. When operating metal halide lamps, a run-up time of several minutes and a longer cooling-down phase before re-ignition must be taken into account.

Dimmer

The dimmer is used for the infinitely variable regulation of the output from a light source. Leading edge control is applied to incandescent lamps. Low-voltage halogen lamps with electronic transformer are dimmed using trailing edge technology. Thermal radiators such as tungsten halogen lamps are easy to dim. Fluorescent lamps require special control gear, while compact fluorescent lamps require special electronic control gear units. Conventional compact fluorescent lamps cannot be dimmed. LEDs can easily be dimmed with the appropriate control gear.

In analogue 1V-10V technology, dimming is possible by using a special ECG with input for the 1V-10V control voltage and a potentiometer or a control system supplying analogue 1V-10V control voltage, such as the ERCO Area Net or KNX actuators. The dimmers are often installed in switch cabinets. The control lines are permanently connected to luminaires or groups of luminaires. The digital control protocol, DALI, on the other hand, allows for the individual control of the dimmable ECGs for all the connected luminaires.

Controller

Controllers are electronic units for process control. A lighting control system such as the Light System DALI saves light scenes and controls the luminaires. The amount of data which can be used to store the settings is limited by the storage capacity of the controller. The user operates the controller via software or a control panel. A control line establishes a connection to the luminaires and transmits the signals to the control gear.

In a LON system, D/A modules are used to save and recall light scenes. As output devices, they allow the connection of external dimmers or direct control of dimmable ECGs or transformers.
Interfaces

Interfaces or ‘Gateways’ enable the exchange of signals and data between different data networks or bus systems. Where several control systems are used in a building, the data needs to be transferred between these systems. Lighting control systems can be integrated as subsystems into a building management system by means of a gateway. In the same manner, gateways can be used, for example, for DALI lighting control systems to activate 1V-10V controllers for the sun screening equipment.

Software

Lighting control software turns any PC connected to a lighting control system into a control panel and programming device for the lighting system. The PC can be connected to the lighting control system using interfacing standards such as USB. The brightness and light colour settings are combined in light scenes. The light scenes are programmed using the software and recalled via control panels. The software can provide many additional functions, such as spatial and timed control. A timer program ensures lighting control according to predefined sequences or calendar settings. With sequential control, the light scenes are repeated in cycles. The calendar function recalls the light scenes according to predetermined times or days. The DALI system with individually addressable luminaires allows flexible allocations and regrouping. The firmware is the software required for the operation of devices and is saved in a flash memory. The PC software is used to operate the lighting control system on the computer and is saved on the hard drive.
The application area for a lighting control consists of the functional adaptation of the individual lighting requirement, the optimisation of the use of energy and the differentiated design of architecture, exhibition and presentation.
Museum

Room of museum for presentation of paintings and sculptures. Requirements: The illuminance level is kept low as long as no visitors are in the room. When someone enters the room the optimum exhibition lighting is switched on.
Planning

Circuit options
Track outside = 3 circuits
Track inside = 2 circuits

Circuit 1/2
Wallwashers with compact fluorescent lamps (switched)
6 x ECO-E 12W BS 9

Circuit 3
Wallwashers with mains voltage
halogen lamps (dimmable)
10 x 150W

Circuit 4/5
Spotlights with PAR 30
(dimmable)
each 2 x 100W PAR 30
Requirements: Several illuminance levels can be set; they are controlled dependent on the daylight. It is operated via push-buttons on the door. A maximum of four different lighting levels can be selected via the push-buttons. The light scenes are defined for different uses according to the illuminances. The actual regulation to the set value within the light scene is performed via the daylight regulation.
Observation
Circuits

The Downlights are connected in a row parallel to the window wall = 3 circuits.

Circuits 1-3
Recessed downlights for compact fluorescent lamp (100W dimmable)
Each 4 of 2 x TC-DEL25W
BUS 1-10V
Observation

Requirements: The lighting program is made up of differentiated light scenes. It is operated via a Preset at the reception. A daylight control optimises the power consumption.
Observation

Planning

Circuits

Wallwasher = 2 circuits
Doorly = 3 circuits
Low-voltage downlights
= 5 circuits (rotating door)

Circuit 1
Wallwasher downlights (dimmable)
6 x 150W

Circuit 2
Wallwasher downlights (dimmable)
8 x 150W

Circuit 3
Low-voltage downlights with 50W
fusgaten halogen lamps (dimmable)
4 x 100W/12V Magnetic trans.

Circuit 4
Spotlights low-voltage 100W
(dimmable)
4 x 100W/12V magnetic

Circuit 5-6
Spotlights HIT 150W
(switch c3)
each 4 x 160W HIT
Restaurant

Observation

Requirement: different light scenes can be recalled at breakfast, lunch and dinner times.
Restaurant

Observation
Guide

Lighting control | Design examples

Restaurant

Planning

Circuits

Circuit 1, 2
Recessed downlight for low-voltage halogen lamps (dimmable)
each 3 x 100W/12V magnetic transformer

Circuit 3
Recessed downlight for low-voltage halogen lamps (dimmable)
8 x 100W/12V magnetic transformer

Circuit 4
Uplighter for halogen lamps (dimmable)
3 x 300W

Circuit 5
Recessed downlight for halogen lamps (dimmable)
6 x 150W

Circuit 6
Recessed wallwasher for halogen lamps (dimmable)
each 8 x 100W

Circuit 7
Recessed downlight for low-voltage halogen lamps (dimmable)
3 x 100W/12V magnetic transformer

Circuit 8
Recessed downlight for low-voltage halogen lamps (dimmable)
10 x 100W/12V magnetic transformer
Observation
Large room

Requirement: Various light scenes for different purposes with different room allocation:
- training/seminar, large room
- meeting, large room
- training, small room
Observation

Large room

Planning

Circuits

Circuit planning must always contain all options. In partitioned rooms, the electrical circuits each side of the partition must be separate.

Circuit 1, 5:
- Downlight for compact fluorescent and low voltage lamps (dimmable)
- each: 12 or 2 x TCD 25W
- EC 0 - 10V

Circuit 2, 6:
- Downlight for compact fluorescent and low voltage lamps (dimmable)
- each: 12 x 35W/12V
- electronic transformer 1 - 10V

Circuits 3, 4, 7, 8:
- Track mounted spotlight 12W/50W
- (Electronic transformer) (dimmable)
- each: 2 x 50W/12V

Check

- Large room
- Small room
Guideline

Lighting control | Design examples

Multifunctional room

Observation
Small room
The spectrum of lighting technology covers information on photometric values, light sources and luminaire technology. These contents aid orientation so that an appropriate technical solution can be found for the lighting task in question.
Light plays a central role in the design of a visual environment. The architecture, people and objects are all made visible by the lighting. Light influences our well-being, the aesthetic effect and the mood of a room or area.
Luminous flux

Luminous flux describes the total light power emitted by a light source. As a rule, this radiant power could be expressed as emitted energy in the unit of watts. However, this method is inadequate for describing the optical effect of a light source, since the emitted radiation is recorded without discrimination over the entire frequency range and the different spectral sensitivity of the eye is not considered. The inclusion of the spectral sensitivity of the eye results in the quantity termed lumen. A radiant flux of 1W emitted at the maximum extent of spectral optical sensitivity (photopic, 555 nm) gives a luminous flux of 683 lm. Conversely, the same radiant flux emitted at frequency ranges of lower sensitivity as per the V (λ) results in correspondingly smaller luminous fluxes.

Φ = lumen (lm)

Luminous efficacy

The luminous efficacy describes the efficacy of a lamp. It is expressed as the ratio of the emitted luminous flux in lumen and the power used in watts. The theoretically attainable maximum value assuming complete conversion of energy at 555 nm would be 683 lm/W. The luminous efficacies that can actually be attained vary depending on the lamp, but always remain far below this ideal value.

η = Φ / P

η = lm / W
**Light intensity**

The light intensity $I$ is a measure for the luminous flux $\Phi$ emitted per solid angle $\Omega$.

$$I = \frac{\Phi}{\Omega}$$

$I$ = lm / sr

lm / sr = Candela [cd]

**Definition**

An ideal, point light source radiates its luminous flux evenly in all directions in the room, with its light intensity being equal in all directions. In practice, however, there is always an uneven spatial distribution of luminous flux, partly due to the lamp design and partly due to the manner in which the luminaire is formed. The Candela, as the unit of light intensity, is the basic unit of lighting engineering from which all other lighting engineering values are derived.

**Representation**

The spatial distribution of the light intensity of a light source results in a three-dimensional body of light intensity distribution. A section through this light intensity body will give the light intensity distribution curve, which describes the light intensity distribution in one plane. The light intensity is, usually displayed in a polar co-ordinate system as a function of the emission angle. To enable direct comparison of the light intensity distribution of different light sources, the values are expressed in relation to $1000\text{lm}$ luminous flux. With rotationally symmetrical luminaires, a single light intensity distribution curve is sufficient to describe the luminaire. Axially symmetrical luminaires need two curves, although, these can usually be represented on one diagram.
Axially symmetrical luminaire

Light intensity distribution form and light intensity distribution curves (planes C 0/180° and C 90/270°) of an axially symmetrically luminaire.

Emission angle

A light intensity distribution curve scaled to 1000 lm, shown in polar coordinates. The angular range within which the maximum light intensity I' decreases to I'/2 denotes the emission angle β. The cut-off angle α brings the limit emission angle YG to 90°.
The illuminance is a measure for the luminous flux density on a surface. It is defined as the ratio of the luminous flux incident on a surface to the size of that surface. The illuminance is not tied to a real surface, it can be determined anywhere in the room. The illuminance can be derived from the light intensity. Whereby, the illuminance reduces by the square of the distance from the light source (inverse square law).

Illuminance $E$ as dimension for the luminous flux per surface area unit $A$

Horizontal illuminance

Horizontal illuminance $E_h$ and vertical illuminance $E_v$ in indoor areas.

Average horizontal illuminance

The average horizontal illuminance $E_m$ is calculated from the luminous flux, incident on the surface in question $A$.

$$E_m = \frac{\Phi}{A}$$

Illuminance at a point

The illuminance at a given point $E_p$ is calculated from the light intensity $I$ and the distance $a$ between the light source and the said point.

$$E_p = \frac{I}{a^2}$$

$[E_p] = \text{lx}$

$I = \text{cd}$

$a = \text{m}$
Exposure is described as the product of the illuminance and the exposure time through which a surface is illuminated. Exposure is an important issue, for example, regarding the calculation of light exposure on exhibits in museums.

Exposure

Exposure is the product of the illuminance and the exposure time through which a surface is illuminated. Exposure is an important issue, for example, regarding the calculation of light exposure on exhibits in museums.

Luminance

Luminance is the ratio of light intensity and the area projected perpendicularly to the emission direction. The light can also be reflected or transmitted by the surface however. For diffuse reflecting (matt) and diffuse transmitting (murky) materials, the luminance can be calculated from the illuminance and the reflectance or transmittance. Brightness correlates with luminance; although, the actual impression of brightness is still influenced by how well the eyes have adapted, by the surrounding contrast levels and by the information content of the viewed surface.

Luminance

Luminance L of a luminous surface is given by the ratio of light intensity I and its projected area Ap.

\[ L = \frac{I}{Ap} \]

\[ [L] = \text{cd} / \text{qm} \]

Whereas illuminance expresses the luminous power incident on a surface, the luminance describes the light given off by this surface. This light can be given off by the surface itself (e.g. when considering luminance of lamps and luminaires). Luminance is defined as the ratio of light intensity and the area projected perpendicularly to the emission direction. The light can also be reflected or transmitted by the surface however. For diffuse reflecting (matt) and diffuse transmitting (murky) materials, the luminance can be calculated from the illuminance and the reflectance or transmittance. Brightness correlates with luminance; although, the actual impression of brightness is still influenced by how well the eyes have adapted, by the surrounding contrast levels and by the information content of the viewed surface.

The luminance L of a luminous surface is given by the ratio of light intensity I and its projected area Ap.

\[ L = \frac{I}{Ap} \]

\[ [L] = \text{cd} / \text{qm} \]

The luminance of a diffusely reflecting illuminated surface is proportional to the illuminance and the reflectance of the surface.

\[ L_1 = \frac{E_h \cdot \rho_1}{p} \]

\[ L_2 = \frac{E_v \cdot \rho_2}{p} \]

\[ [L] = \text{cd} / \text{qm} \]

\[ [E] = \text{lx} \]
Light colour is the colour of the light emitted by a lamp. Light colour can be expressed using \(x, y\) coordinates as chromaticity coordinates in a standard colorimetric system, or, for white light colours, it can also be given as the colour temperature \(T_\text{F}\). In the CIE standard colorimetric system, the colour of light is calculated from the spectral constitution and represented in a continuous, two-dimensional diagram. The hue is defined via the chromaticity coordinates of the spectral colour and via the saturation level. The design of the diagram features a coloured area that contains every possible real colour. The coloured area is encompassed by a curve on which the chromaticity locations of the completely saturated spectral colours lie. At the centre of the area is the point of least saturation, which is designated as a white or uncoloured point. All levels of saturation of one colour can now be found on the straight lines between the uncoloured point and the chromaticity location in question. Similarly, all mixtures of two colours are likewise to be found on a straight line between the two chromaticity locations in question.

**Planck’s curve with the host of lines**
Section from the coloured area with Planck’s curve and the host of lines of chromaticity locations of the same (closest) colour temperature between 1600 and 10000K. The ranges of the light colours warm white (ww), neutral white (nw) and daylight white (dw) are shown.

**Planck’s curve with typical light sources**
Section from the coloured area with Planck’s curve and the chromaticity locations of the standard types of light A (incandescent lamp light) and D 65 (daylight) as well as the chromaticity locations of typical light sources: candle flame (1), incandescent lamp (2), tungsten halogen lamp (3), fluorescent lamps ww (4), nw (5) and dw (6).

**Closest colour temperature**
Planck’s curve contains the chromaticity locations of Planck’s radiation of all temperatures. Since the chromaticity location of a light source often lies near to the curve, starting from the curve of Planck’s radiator, a host of straight lines of the closest colour temperatures is added. With their help, even those light colours that are not on this line can be identified by the closest colour temperature. On temperature radiators, the closest colour temperature corresponds to something approaching the actual temperature of the lamp filament. On discharge lamps, the closest colour temperature is stated.
In addition, white colours of light are divided into three main groups: the warm white range (ww) with the closest colour temperatures below 4000K, the neutral white range (nw) between 4000 and 5000K and the daylight white range (dw) with the closest colour temperatures over 5000K. The same colours of light may have different spectral distributions and a correspondingly different colour rendition.

### Main groups colour temperatures

<table>
<thead>
<tr>
<th>Light source</th>
<th>T (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Candle</td>
<td>1900–1950</td>
</tr>
<tr>
<td>Carbon filament lamp</td>
<td>2100</td>
</tr>
<tr>
<td>Incandescent lamp</td>
<td>2700–2900</td>
</tr>
<tr>
<td>Fluorescent lamps</td>
<td>2800–7500</td>
</tr>
<tr>
<td>Moonlight</td>
<td>4100</td>
</tr>
<tr>
<td>Sunlight</td>
<td>5000–6000</td>
</tr>
<tr>
<td>Daylight (sunshine, blue sky)</td>
<td>5800–6500</td>
</tr>
<tr>
<td>Overcast sky</td>
<td>6400–6900</td>
</tr>
<tr>
<td>Clear blue sky</td>
<td>10000–26000</td>
</tr>
</tbody>
</table>

### Closest colour temperature T

- **Warm white**
- **Neutral white**
- **Daylight white**
Colour rendition

Colour rendition refers to the quality of the reproduction of colours under a given illumination. The degree of colour distortion is indicated using the colour rendition index Ra and/or the colour rendition grading system. A comparative light source with continuous spectrum serves as a reference light source, whether this be a temperature radiator of comparable colour temperature or the daylight.

To enable the colour rendition of a light source to be determined, the chromatic effects of a scale of eight body colours viewed under the type of illumination being scrutinised and also under the reference illumination are calculated and related to each other. The resulting quality of colour rendition is expressed in colour rendition indices; these can relate both to the general colour rendition (Ra) as an average value or to the rendition of individual colours. The maximum index of 100 signifies ideal colour rendition as experienced with incandescent lamp light or daylight. Lower values refer to a correspondingly worse colour rendition. Linear spectra of light lead to good colour rendition. Linear spectra in general lead to a worse rendition. Multiline spectra are composed of several different linear spectra and improve the colour rendition.

Colour rendition index

<table>
<thead>
<tr>
<th>Lamp Type</th>
<th>20</th>
<th>40</th>
<th>60</th>
<th>80</th>
<th>100</th>
<th>Ra</th>
</tr>
</thead>
<tbody>
<tr>
<td>LED</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>QT (12V)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>QT</td>
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</tr>
<tr>
<td>TC</td>
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<td>T</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>HIT</td>
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<tr>
<td>HST</td>
<td></td>
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</tr>
</tbody>
</table>

Ranges of the colour rendition index Ra for different lamp types
Guide

Lighting technology

Lamps

Having technical knowledge about lamps will help to make the right selection with regards to brilliance, colour rendition, modelling ability and energy efficiency. The spectrum ranges from thermal radiators through to semiconductor spotlights.

Lamps, general    Thermal radiators    Discharge lamps

Electroluminescent radiators
The electric light sources can be divided into three main groups, divided according to how they convert electrical energy into light. One group is that of the thermal radiators, this contains incandescent lamps and tungsten halogen lamps. The second group is made up of the discharge lamps; this consists of a large spectrum of light sources, e.g. all forms of fluorescent lamps, sodium vapour lamps and metal halide lamps. The third group consists of the semiconductors with the LEDs.
### Lamp overview

<table>
<thead>
<tr>
<th>Lamp power P (W)</th>
<th>LED</th>
<th>A</th>
<th>QT (12V)</th>
<th>QT</th>
<th>TC</th>
<th>T</th>
<th>HIT</th>
<th>HST</th>
</tr>
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<tbody>
<tr>
<td>2-48</td>
<td>100</td>
<td>20-100</td>
<td>80-1000</td>
<td>9-55</td>
<td>24-54</td>
<td>20-400</td>
<td>50-100</td>
<td></td>
</tr>
<tr>
<td>160-4800</td>
<td>58</td>
<td>1380</td>
<td>320-2200</td>
<td>1450-22000</td>
<td>600-4800</td>
<td>1750-4450</td>
<td>1800-35000</td>
<td>2400-4900</td>
</tr>
<tr>
<td>100</td>
<td>15</td>
<td>22</td>
<td>22</td>
<td>78</td>
<td>90</td>
<td>114</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>various</td>
<td>ww</td>
<td>ww</td>
<td>ww</td>
<td>ww, nw, dw</td>
<td>ww, nw, dw</td>
<td>ww, nw</td>
<td>ww</td>
<td></td>
</tr>
<tr>
<td>1700-10000</td>
<td>2700</td>
<td>3000</td>
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<td>2700-6500</td>
<td>2700-6500</td>
<td>3000-4200</td>
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<td>1b</td>
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<td>80-90</td>
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<td>80-82</td>
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<td>81-90</td>
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<td>50000</td>
<td>1000</td>
<td>4000</td>
<td>2000</td>
<td>12000-13000</td>
<td>18000-20000</td>
<td>5000-15000</td>
<td>10000</td>
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<tr>
<td>Dimming behavior</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td></td>
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<tr>
<td>Brilliance</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Start up behavior</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

**Lamp power P (W)**: Wattage of the lamp.
**LED**: Light Emitting Diode
**A**: Amperage
**QT (12V)**: Quiescent Power (12V)
**QT**: Quiescent Temperature
**TC**: Tolerance of Change
**T**: Temperature
**HIT**: High Initial Temperature
**HST**: High Service Temperature
**Light colour**: Various, warm white (ww), warm white (ww), warm white (ww), warm white (ww), warm white (ww), daylight white (dw), warm white (ww), daylight white (dw), warm white (ww), daylight white (dw)
**Colour temperature TF (K)**: Kelvin temperature
**Colour rendition index Ra**: Colour rendering index
**Service life t (h)**: Hours of service life
**Dimming behavior**: + for adjustable dimming, - for non-dimmable
**Brilliance**: + for high brilliance, - for low brilliance
**Start up behavior**: + for good start up, - for poor start up

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## Guide

### Lamp designation

<table>
<thead>
<tr>
<th>Lamp designation</th>
<th>Letter code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>General service lamp</td>
<td>(I) (G) A</td>
<td>A</td>
</tr>
<tr>
<td>Parabolic reflector lamp</td>
<td>(I) (G) PAR</td>
<td>PAR</td>
</tr>
<tr>
<td>Reflector lamp</td>
<td>(I) (G) R</td>
<td>R</td>
</tr>
<tr>
<td>Halogen reflector lamp</td>
<td>(I) Q R</td>
<td>QR</td>
</tr>
<tr>
<td>Tungsten halogen lamp in tubular form</td>
<td>(I) Q T</td>
<td>QT</td>
</tr>
<tr>
<td>Mercury vapour lamp (ellipsoidal)</td>
<td>H M E</td>
<td>HME</td>
</tr>
<tr>
<td>Mercury vapour lamp (reflector form)</td>
<td>H M R</td>
<td>HMR</td>
</tr>
<tr>
<td>Metal halide lamp (ellipsoidal)</td>
<td>H I E</td>
<td>HIE</td>
</tr>
<tr>
<td>Metal halide lamp (reflector form)</td>
<td>H I R</td>
<td>HIR</td>
</tr>
<tr>
<td>Metal halide lamp (tubular)</td>
<td>H I T</td>
<td>HIT</td>
</tr>
<tr>
<td>High-pressure sodium vapour lamp (ellipsoidal)</td>
<td>H S E</td>
<td>HSE</td>
</tr>
<tr>
<td>High-pressure sodium vapour lamp (tubular)</td>
<td>H S T</td>
<td>HST</td>
</tr>
<tr>
<td>Flourescent lamp</td>
<td>(L) (M) T</td>
<td>T</td>
</tr>
<tr>
<td>Compact fluorescent lamp</td>
<td>(L) (M) TC</td>
<td>TC</td>
</tr>
<tr>
<td>Low-pressure sodium vapour lamp</td>
<td>L S T</td>
<td>LST</td>
</tr>
<tr>
<td>Tungsten halogen lamp, double ended</td>
<td>QT-DE</td>
<td></td>
</tr>
<tr>
<td>Halogen reflector lamp, coolbeam, open front</td>
<td>QR-CB</td>
<td></td>
</tr>
<tr>
<td>Halogen reflector lamp, coolbeam, closed front</td>
<td>QR-CBC</td>
<td></td>
</tr>
<tr>
<td>Metal halide lamp, double ended</td>
<td>HIT-DE</td>
<td></td>
</tr>
<tr>
<td>Compact fluorescent lamp</td>
<td>TC</td>
<td></td>
</tr>
<tr>
<td>- without starter for electronic control gear</td>
<td>TC-EL</td>
<td></td>
</tr>
<tr>
<td>- with 4x tube</td>
<td>TC-D</td>
<td></td>
</tr>
<tr>
<td>- with 4x tube, with built-in electronic control gear</td>
<td>TC-DSE</td>
<td></td>
</tr>
<tr>
<td>- with 4x tubes, without starter elect. control gear</td>
<td>TC-DEL</td>
<td></td>
</tr>
<tr>
<td>- long design</td>
<td>TC-L</td>
<td></td>
</tr>
</tbody>
</table>

### Letter code

The 1\(^{st}\) letter refers to the method of light generation.

The 2\(^{nd}\) letter identifies the bulb material on incandescent lamps or the gas fillings on discharge lamps.

The 3\(^{rd}\) letter or combination of letters refers to the bulb shape.

<table>
<thead>
<tr>
<th>Letter</th>
<th>Incandescent lamp</th>
<th>High-pressure discharge lamp</th>
<th>Low-pressure discharge lamp</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Glass</td>
<td>Q Quartz glass</td>
<td>M Mercury</td>
</tr>
<tr>
<td></td>
<td>I Metal halide</td>
<td></td>
<td>I</td>
</tr>
<tr>
<td>S</td>
<td>Sodium vapour</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

|        | All-purpose           | Ellipsoid                    | Parabolic reflector         |
| A      |                       | E Ellipsoid                  | E PAR Ellipsoid             |
|        |                       | R Reflector                  | R PAR Reflector             |
|        |                       | T Tube                       | T PAR Tube                  |
|        |                       | TC Compact tube              | TC PAR Compact tube         |
Thermal radiators generate light by using an incandescent metal filament. As the temperature increases the spectrum of light shifts from the red heat of the filament to warm white light. Characteristic features are low colour temperature, excellent colour rendition and brilliance as a point light source.

- General service lamps
- R and PAR lamps
- Tungsten halogen lamps
- Halogen reflector lamps
A low colour temperature is characteristic for the general service lamp. It is perceived as being warm. The continuous spectrum of the incandescent lamp results in an excellent colour rendition. As a point light source with high luminance it produces brilliance. Incandescent lamps can be dimmed without problem. They do not require any additional equipment for their operation. The disadvantages of incandescent lamps are low luminous efficacy and a relatively brief nominal service life.

The general service lamp is a thermal radiator. Electrical current causes a metal filament to glow. Part of the radiated energy is visible as light. When dimming, the reducing temperature causes the light spectrum to shift towards the range of longer wavelengths – the warm white light of the incandescent lamp changes to the red heat of the filament. The maximum radiation is in the infrared range. A lot of thermal radiation is generated in comparison to the visible component; conversely there is very little UV radiation. The continuous spectrum of the incandescent lamp results in an excellent colour rendition.

Incandescent lamps are available as A-lamps (All-purpose lamps) in many forms. Their bulbs can be clear, matt or white. The light is emitted in all directions.
Guide

Lighting technology | Lamps | Thermal radiators

R and PAR lamps

Properties

A low colour temperature is characteristic for the reflector and parabolic aluminised reflector lamps. The continuous spectrum of the incandescent lamp results in an excellent colour rendition. As a point light source with high luminance it produces brilliance. They do not require any additional equipment for their operation.

Physics

The incandescent lamp is a thermal radiator. Electrical current causes a metal filament to glow. Part of the radiated energy is visible as light. When dimming, the reducing temperature causes the light spectrum to shift towards the range of longer wavelengths – the warm white light of the incandescent lamp changes to the red heat of the filament. The maximum radiation is in the infrared range. A lot of thermal radiation is generated in comparison to the visible component; conversely there is very little UV radiation. The continuous spectrum of the incandescent lamp results in an excellent colour rendition.

Shapes

The R (Reflector) lamps are blown from soft glass and direct the light due to their shape and a partial mirror coating on the inside.

The PAR lamps are manufactured from pressed glass in order to achieve high resistance to temperature change and high accuracy of shape. The parabolic reflector is available with different half peak spreads and produces a defined beam emission angle. On coolbeam lamps, a subgroup of the PAR lamps, a dichroic mirror coating is used. Dichroic reflectors focus the visible light but allow a large part of the thermal radiation to pass through unaffected. This allows the thermal load on the illuminated objects to be reduced by approximately half.

The disadvantages of incandescent lamps are low luminous efficacy and a relatively brief nominal service life.

Relative spectral distribution

Colour temperature


Shapes

Left: reflector lamp with soft glass bulb and ellipsoid reflector with moderate focusing power.
Right: reflector lamp with pressed glass bulb and powerful parabolic reflector.
Guide

Lighting technology | Lamps | Thermal radiators

Tungsten halogen lamps

**Properties**

The tungsten halogen lamp emits a whiter light than conventional incandescent lamps. Its light colour is in the range of warm white. Due to the continuous spectrum, the colour rendition is excellent. Its compact form makes the tungsten halogen lamp an ideal point light source. The particularly good directability of the light produces brilliance. The luminous efficacy and life of tungsten halogen lamps is above that of ordinary incandescent lamps. Tungsten halogen lamps can be dimmed and do not require any additional control gear; low-voltage halogen lamps, however, must be powered via transformers.

**Physics**

Halogens in the gas filling reduce the material loses of the filament caused by evaporation and increase the performance of the lamp. The evaporated tungsten combines with the halogen to form a metal halide, and is channelled back to the filament. The lamp’s compact shape not only enables the temperature to increase but also allows an increase in the gas pressure, which reduces the tungsten’s rate of evaporation. As the temperature increases the light spectrum shifts towards the short wavelength range – the red heat of the filament becomes the warm white light of the incandescent lamp. A lot of thermal radiation is generated in comparison to the visible component; conversely there is very little UV radiation. The tungsten halogen reflector lamp emits a continuous spectrum and thus produces an excellent colour rendition.

**Shapes**

From left to right: tungsten halogen lamp for nominal voltage with E27 fixing and enveloping capsule, with bayonet fixing, with double-ended fixing. Low-voltage halogen lamp with axial filament. Tungsten halogen lamps are available for operation on mains voltage. They usually have a special fixing. Some feature a screw fixing and an additional external glass capsule and can be used just like conventional incandescent lamps. The advantages of the low-voltage halogen lamp primarily concern the high luminous power for its small dimensions. The lamp enables compact luminaire designs and a very narrow focussing of the light. Low-voltage halogen lamps are available for different voltages and in various shapes and must be powered via transformers. The lamps emit light in all directions. Halogen lamps with low-pressure technology are permitted for all corresponding luminaires. Halogen lamps without low-pressure technology are only permitted in luminaires with protective cover. The advantages of the low-pressure version are improved luminous flux throughout the entire service life.
Halogen reflector lamps

Properties

The tungsten halogen reflector lamp emits a whiter light than conventional incandescent lamps. Its light colour is in the range of warm white. Due to the continuous spectrum, the colour rendition is excellent. Its compact form makes the tungsten halogen reflector lamp an ideal point light source. The particularly good directability of the light produces brilliance. The luminous efficacy and life of tungsten halogen reflector lamps is above that of ordinary incandescent lamps. Tungsten halogen reflector lamps can be dimmed.

Physics

Halogens in the gas filling reduces the material loses of the filament caused by evaporation and increase the performance of the lamp. The evaporated tungsten combines with the halogen to form a metal halide, and is channelled back to the filament. The lamp's compact shape not only enables the temperature to increase but also allows an increase in the gas pressure, which reduces the tungsten's rate of evaporation. As the temperature increases the light spectrum shifts towards the short wavelength range the red heat of the filament becomes the warm white light of the incandescent lamp. A lot of thermal radiation is generated in comparison to the visible component; conversely there is very little UV radiation. The tungsten halogen reflector lamp emits a continuous spectrum and thus produces an excellent colour rendition.

Shapes

Low-voltage halogen lamp with pin base and coolbeam reflector made of glass, with aluminium reflector for higher performance.

Tungsten halogen reflector lamps are available for operation on mains voltage. They usually have a special fixing. Some feature a screw fixing and an additional external glass capsule and can be used just like conventional incandescent lamps. The advantages of the low-voltage halogen lamp primarily concern the high luminous power for its small dimensions. The lamp enables compact luminaire designs and a very narrow focussing of the light. Low-voltage halogen reflector lamps are available for different voltages and in various shapes and must be powered via transformers. They are available with different half peak spreads. The versions with coolbeam reflectors radiate the heat away to the sides and reduce the thermal loading in the focused beam. The halogen parabolic reflector lamp combines the advantages of halogen technology with the technology of the PAR lamps.

Discharge lamps comprise those light sources whereby the generation of light does not rely, or does not solely rely, on the temperature of the materials. Depending on the type, a differentiation is made between photo luminescence and electroluminescence. The light is generated principally using chemical or electrical processes. The discharge lamp group is subdivided into low-pressure and high-pressure lamps.
Fluorescent lamps

Properties

With fluorescent lamps, the light is emitted from a large surface and is mainly diffuse light with little brilliance. The light colours of fluorescent lamps are warm white, neutral white and daylight white. fluorescent lamps feature a high luminous efficacy and long life. Both starters and control gear (chokes) are necessary for operating fluorescent lamps. They ignite immediately and attain their full luminous power after a brief moment. An immediate re-ignition is possible if the current is interrupted. Fluorescent lamps can be dimmed depending on the control gear.

Technology

The electrode (1) releases electrons (2) that then collide into mercury atoms (3). This causes the electrons of the mercury atom (4) to become excited, causing them to emit UV radiation (5). In the fluorescent coating (6), the UV radiation is converted into visible light (7).

Physics

The fluorescent lamp is a low-pressure discharge lamp that works using mercury. The gas filling consists of an inert gas that makes the ignition easier and controls the discharge. The mercury vapour emits ultraviolet radiation upon excitation. Fluorescent substances on the inside surface of the discharge tube convert the ultraviolet radiation into visible light using fluorescence. A voltage surge is used to ignite the lamp. The discontinuous spectrum of fluorescent lamps has a poorer colour rendition property than that of incandescent lamps with a continuous spectrum. The colour rendition of fluorescent lamps can be improved at the cost of luminous efficacy. Conversely, increasing the luminous efficacy causes a worsening of the colour rendition. The light colour can be in the warm white, neutral white or daylight white range, depending on the proportion of the individual fluorescent substances.
Guide
Lighting technology | Lamps | Discharge lamps
Fluorescent lamps

Physics

Shapes

Fluorescent lamps are usually shaped as a straight tube, whereby the luminous power depends on the length of the lamp. Special forms such as U-shape or ring-shape fluorescent lamps are available.

T26  18W, 36W, 58W

T16  14W, 35W, 54W
**Properties**

By bending or coiling the discharge tubes, compact fluorescent lamps are made shorter than ordinary fluorescent lamps. They have fundamentally the same properties as the conventional fluorescent lamps, above all these are high luminous efficacy and long life. The relatively small volume of the discharge tubes can produce a focused light using the luminaire’s reflector. Compact fluorescent lamps with integrated starters cannot be dimmed. However, there are types with external starter available, which can be operated on electronic control gear and allow dimming.

**Physics**

The fluorescent lamp is a low-pressure discharge lamp that works using mercury. The gas filling consists of an inert gas that makes the ignition easier and controls the discharge. The mercury vapour emits ultraviolet radiation upon excitation. Fluorescent substances on the inside surface of the discharge tube convert the ultraviolet radiation into visible light using fluorescence. A voltage surge is used to ignite the lamp. The discontinuous spectrum of fluorescent lamps has a poorer colour rendition property than that of incandescent lamps with continuous spectrums. The colour rendition of fluorescent lamps can be improved at the cost of luminous efficacy. Conversely, increasing the luminous efficacy causes a worsening of the colour rendition. The light colour can be in the warm white, neutral white or daylight white range, depending on the proportion of the individual fluorescent substances.
Guide

Lighting technology | Lamps | Discharge lamps
Compact fluorescent lamps

Physics

Relative spectral distribution

Colour temperature
warm white

Relative spectral distribution

Colour temperature
neutral white

Shapes

Compact fluorescent lamps are primarily available as a straight tube. Starters and fluorescent lamp chokes are necessary for their operation; on two pin lamps, however, the starters are already integrated into the end cap. In addition to these standard forms, there are also compact fluorescent lamps with integrated starter and control gear. These features a screw-in fixing and can be used just like incandescent lamps.
Metal vapour lamps

Metal halide lamps feature excellent luminous efficacy while simultaneously having good colour rendition; their nominal service life is high. They represent a compact light source. The light can be optically well directed. The colour rendition is not constant. Metal halide lamps are available in the light colours warm white, neutral white and daylight white and are not dimmed. Metal halide lamps require both starters and chokes for their operation. They require an ignition time of several minutes and a longer cooling-down phase before re-igniting.

On some forms an immediate re-ignition is possible using special starters or the electronic control gear.

Properties

Metal halide lamps are comparable with high-pressure mercury vapour lamps in design and function. They additionally contain a mixture of metal halides. In addition to increasing the luminous efficacy, improved colour rendition is also attained. Due to combinations of metals, an almost continuous multiline spectrum is produced. Metal halide lamps are available in the light colours warm white, neutral white and daylight white. Compared to quartz technology, the lamps with ceramic discharge tube feature higher luminous efficacy and better colour rendition due to the increased operating temperature.

Physics

Relative spectral distribution

Colour temperature

Warm white

Neutral white

Relative spectral distribution
Metal halide lamps are available as single-ended or doubled-ended tubular lamps, as elliptical lamps and as reflector lamps. Metal halide reflector lamps combine the technology of the metal halide lamps with that of the PAR lamps.
High-pressure sodium vapour lamps

Properties

High-pressure sodium vapour lamps have excellent luminous efficacy and a high nominal service life. Their colour rendition is moderate to good. High-pressure sodium vapour lamps are operated with a control gear and a starter. They require an ignition time of several minutes and a cooling-down phase before being re-ignited. On some forms an immediate re-ignition is possible using special starters or the electronic control gear.

Physics

High-pressure sodium vapour lamps are comparable with the high-pressure mercury vapour lamps in design and function. The mixture inside the lamps consists of inert gases and a mercury-sodium amalgam, whereby the inert gas and mercury component serves the ignition and stabilisation of the discharge. When the pressure is sufficiently high, a virtually continuous spectrum is produced with a yellowish to warm white light while giving moderate to good colour rendition.

Shapes

High-pressure sodium vapour lamps are available as clear lamps in tubular form and as coated lamps in ellipsoid form. Furthermore, there are also double-ended compact straight tube lamps, which allow immediate re-ignition and represent a particularly compact light source. One part of the high-pressure sodium vapour lamps has a coated outer capsule. This coating serves only to reduce the lamp luminance and to give a more diffuse light emission, it does not contain any fluorescent substances.
In electroluminescent radiators, the electrical energy produces visible radiation. One of the characteristic aspects of light emitting diodes, LEDs, is their narrow banded spectrum, while their advantages include a compact shape, high colour density, a long life, and low power consumption.
LED

Properties

Light emitting diodes, LEDs, have extremely long life, impact resistance and low energy consumption. When dimmed, the light colour remains constant. When connected to the mains, they require control gear to ensure the correct operating current. The point light source provides for precise light control while the plastic encapsulation of the diode acts as protection and lens. The output of the LED decreases with increasing temperature. Consequently, good heat dissipation is important for smooth operation. Direct solar radiation should be avoided so too installation near other sources of heat. With an average rated life of 50,000 hours, LEDs are suitable for long operating times. As they start instantly and react directly to control, they are ideal for quick, dynamic light scenes. The development of LEDs currently focuses on more compact shapes, a higher luminous flux, and better luminous efficacy as well as a more economical production process. A further goal is the reduction of production-related colour deviations. Manufacturers sort LEDs by luminous flux and dominant wavelength and give them a bin code and a rating. This sorting of LEDs is called binning.

Physics

When voltage is applied to the cathode and the anode, the LED emits light from the barrier layer. Electrons change their energy level and through recombination release photons at the pn-junction. The wavelength of the light produced depends on the semiconductor materials.

General

LEDs are semiconductor diodes that belong to the group of electroluminescent sources. The light is generated by recombining charge-carrier pairs in a semiconductor with an appropriate energy band gap. LEDs produce narrow-band radiation. The colour temperature remains constant as the light intensity decreases. LEDs used for lighting do not produce UV or IR radiation.

Coloured LEDs

LEDs produce a narrow banded spectral range. The dominant wavelength determines the colour locus of the LED. Compared to coloured fluorescent lamps, LEDs have a higher colour density. The composition of the semiconductor material determines the light spectrum emitted. Differently coloured LEDs of the same connected load produce different levels of luminous flux.
**Shapes**

**T-type LED**
The standard T-type LED has a plastic housing measuring 3-5mm for the wired LED. The shape of the lens determines the light emission angle. As a light source with a low luminous flux it is used as an orientation or a signal luminaire.

**SMD LED**
With the "Surface Mounted Device" (SMD) shape, the component is glued directly to the circuit board and the contacts are soldered.

**COB LED**
The "Chip on Board" (COB) technology places the chip directly on a circuit board without its own housing. The anode and cathode contact can be made using thin wires. The chip is sealed to protect it.

---

**White LED**
White light cannot be produced with semiconductor materials. Consequently, white light is currently generated using two methods: RGB mixing or luminescence conversion. The colour rendition of white LEDs currently approximates a colour rendition index Ra of 90. The light colours available include warm white, neutral white, and daylight white LEDs of 2500K to 8000K.

**RGB LED**
By combining three light diodes with the light colours red, green and blue (RGB), the light colours can be mixed to produce a wide range of colours, including white. The red, green and blue LEDs can be controlled to adjust their different light intensities.

**Luminescence conversion**
The spectrum of coloured LEDs can be converted by using phosphors as a luminous layer. Producing blue LEDs with yellow phosphors is easier than UV LEDs with RGB phosphors.
Luminaires perform a range of functions. The most important task of a luminaire is to direct the lamp’s luminous flux. The objective here is to distribute light in a way that best suits the particular tasks of the luminaire while making the best possible use of the energy expended. In addition to design-related aspects of luminaires as a constituent part of a building’s architecture, those aspects relating to installation and safety are also relevant.
The most essential task of a luminaire is to direct the lamp lumens; whereby, a light distribution is striven for that corresponds to the particular job of the luminaire for the best possible utilisation of the energy used.

A step towards a targeted and specific light control was realised by the introduction of the reflector lamps and PAR lamps. The light is focused by reflectors integrated into the lamp and can be directed in the desired direction with defined beam emission angles. The demand for more differentiated lighting control, for enhanced luminaire efficiency and improved glare limitation led to the reflector being taken from the lamp and integrated into the luminaire. This means that it is possible to construct luminaires that are designed to meet the specific requirements of the light source and the task.
Reflectance

In the case of reflection, the light incident on a surface is fully or partially reflected, depending on the reflection factor of the surface. Besides reflectance, the degree of diffusion of the reflected light is also significant. In the case of specular surfaces, there is no diffusion. The greater the diffusing power of the reflecting surface, the smaller the specular component of the reflected light, up to the point of completely diffused reflection where only diffuse light is reflected.

Luminous intensity distribution $I$ in the case of diffuse reflection

Luminous distribution $L$ in the case of diffuse reflection. It is the same from all angles of vision.

Luminous intensity distribution in the case of mixed reflection

Luminous intensity distribution in the case of specular reflection

Specular reflection is a key factor in the construction of luminaires; by using suitable reflector contours and surfaces, it enables a targeted control of light and is also responsible for the magnitude of the light output ratio.

Specular reflection of parallel beams of light falling onto a flat surface (parallel optical path)

Concave surface (converging beam)

Convex surface (diverging beam)
## Reflectances of common metals, paints and building materials

<table>
<thead>
<tr>
<th>Reflectances</th>
<th>Reflectance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Metals</strong></td>
<td></td>
</tr>
<tr>
<td>Aluminium, highly specular</td>
<td>0.80–0.85</td>
</tr>
<tr>
<td>Aluminium, anodised, matt finish</td>
<td>0.75–0.85</td>
</tr>
<tr>
<td>Aluminium, matt finish</td>
<td>0.50–0.75</td>
</tr>
<tr>
<td>Silver, polished</td>
<td>0.90</td>
</tr>
<tr>
<td>Copper, polished</td>
<td>0.60–0.70</td>
</tr>
<tr>
<td>Chrome, polished</td>
<td>0.60–0.70</td>
</tr>
<tr>
<td>Steel, polished</td>
<td>0.50–0.60</td>
</tr>
<tr>
<td><strong>Paint finish</strong></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>0.70–0.80</td>
</tr>
<tr>
<td>Pale yellow</td>
<td>0.60–0.70</td>
</tr>
<tr>
<td>Pale green, light red, pale blue, light grey</td>
<td>0.40–0.50</td>
</tr>
<tr>
<td>Beige, ochre, orange, mid-grey</td>
<td>0.25–0.35</td>
</tr>
<tr>
<td>dark grey, dark red, dark blue, dark green</td>
<td>0.10–0.20</td>
</tr>
<tr>
<td><strong>Building materials</strong></td>
<td></td>
</tr>
<tr>
<td>Plaster, white</td>
<td>0.70–0.85</td>
</tr>
<tr>
<td>Gypsum</td>
<td>0.70–0.80</td>
</tr>
<tr>
<td>Enamel, white</td>
<td>0.60–0.70</td>
</tr>
<tr>
<td>Mortar, light</td>
<td>0.40–0.50</td>
</tr>
<tr>
<td>Concrete</td>
<td>0.30–0.50</td>
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<tr>
<td>Granite</td>
<td>0.10–0.30</td>
</tr>
<tr>
<td>Brick, red</td>
<td>0.10–0.20</td>
</tr>
<tr>
<td>Glass, clear</td>
<td>0.05–0.01</td>
</tr>
</tbody>
</table>
Transmission describes how the light incident on a body is totally or partially transmitted depending on the transmission factor of the given body. The degree of diffusion of the transmitted light must also be taken into account. In the case of completely transparent materials there is no diffusion. The greater the diffusing power, the smaller the directed component of the transmitted light, up to the point where only diffuse light is produced. Transmitting materials in luminaires can be transparent. This applies to simple front glass panels or filters that absorb certain spectral regions but transmit others, thereby producing coloured light or a reduction in the UV or IR range. Occasionally diffusing materials, e.g. opal glass or opal plastics, are used for front covers in order to reduce lamp luminance and to help control glare.

Absorption describes how the light incident on a surface is totally or partially absorbed depending on the absorption factor of the given material. In the construction of luminaires, absorption is primarily used for shielding light sources; in this regard it is essential for visual comfort. In principle, however, absorption is not desirable since it does not direct but rather wastes light, thereby reducing the light output ratio of the luminaire. Typical absorbing elements on a luminaire are black multigroove baffles, anti-dazzle cylinders, barn doors or louvres of various shapes and sizes.
Refraction

When beams of light enter a clear transmitting medium of differing density, e.g. from air into glass and vice versa from glass into the air, they are refracted, i.e. the direction of their path is changed. In the case of objects with parallel surfaces there is only a parallel light shift, whereas prisms and lenses give rise to optical effects ranging from change of radiation angle to the concentration or diffusion of light to the creation of optical images. In the construction of luminaires refracting elements such as prisms or lenses are frequently used in combination with reflectors to control the light.

When transmitted from one medium with a refractive index of $n_1$ into a denser medium with a refractive index of $n_2$, the rays of light are diffracted towards the axis of incidence ($\varepsilon_1 > \varepsilon_2$). For the transition from air to glass the refractive index is approx. $n_2/n_1 = 1.5$.

When transmitted through a medium of a different density, rays are displaced in parallel.

Prisms and lenses

Typical ray tracing of parallel incident light through an asymmetrical prism structure (top left), symmetrical ribbed prism structure (top right), Fresnel lens (bottom left) and collecting lens (bottom right).

Refractive index

There is an angular limit $\varepsilon_G$ for the transmission of a ray of light from a medium with a refractive index of $n_2$ into a medium of less density with a refractive index of $n_1$. If this critical angle is exceeded the ray of light is reflected into the denser medium (total internal reflection). For the transition from glass to air the angular limit is approx. $\varepsilon_G = 42\degree$. Fibre-optic conductors function according to the principle of total internal reflection (right).
Interference is described as the intensification or attenuation of light when waves are superimposed. From the lighting point of view, interference effects are exploited when light falls on extremely thin layers that lead to specific frequency ranges being reflected and others being transmitted. By arranging the sequence of thin layers of metal vapour according to defined thicknesses and densities, selective reflectance can be produced for specific frequency ranges. The result can be that visible light is reflected and infrared radiation transmitted, for example – as is the case with cool-beam lamps. Reflectors and filters designed to produce coloured light can be manufactured using this technique. Interference filters, so-called dichroic filters, have a high transmission factor and produce particularly distinct separation of reflected and transmitted spectral ranges. Mirror-finish reflectors with good material quality are free of interference.
Reflectors are probably the most important elements in the construction of luminaires for controlling light. Reflectors with mirrored surfaces are mainly used. Diffusely reflective surfaces – usually white or with a matt finish are also used.

Reflectors – general
Parabolic reflectors
Darklight reflectors

Spherical reflectors
Involute reflectors
Elliptical reflectors

Double reflector systems
Reflectors – general

Anodized aluminium or chrome-plated or aluminium-coated plastic are generally used for reflectors. Plastic reflectors are reasonably low-priced, but can only take a limited thermal load and are therefore not so robust as aluminium reflectors, whose highly resistant anodized coating provides mechanical protection and can be subjected to high temperatures.

Material

The surfaces of the reflectors can have a specular or matt finish. The matt finish produces greater and more uniform reflector luminance. If the reflected light beam is to be slightly diffuse, be it to attain softer light or to balance out irregularities in the light distribution, the reflector surfaces may have a facetted or textured finish. Metal reflectors may receive a dichroic coating, which can control light luminous colour or the UV or IR component.

Surface

Reflector surfaces: specular
Matt
Textured
Facetted
Reflectors can be divided into different reflectance groups: mirror-finish, specular and satin matt. Mirror-finish reflectors with good material quality are free of interference. The high reflectance and the highest specular quality make the luminaire appear as a “dark hole” in the ceiling. Reflections of items such as bright room furnishings are possible in the reflector. A further characteristic is high luminance contrasts in the reflector.

The lower specular quality of specular reflectors reduces the disadvantages associated with highly specular reflectors. Satin-matt reflectors are also interference free if the anodising thickness is sufficient. The high reflectance and the low specular quality lead to low contrast within the reflector. This means that disturbing reflections from room furnishings are prevented and it also produces a calm room ambiance. Diffuse surface reflection can cause luminances of >200cd/m² in the area beyond the cut-off angle. There is usually no disturbance on VDU screens.

Geometry

Path of beam from point light sources when reflected by:

- Circle
- Ellipse
- Parabola
- Hyperbola

Light distribution is determined to a large extent by the form of the reflector. Almost all reflector shapes can be attributed to the parabola, the circle or the ellipse.
The most widely used reflectors are parabolic reflectors. They allow light to be controlled in a variety of ways, e.g. narrow-beam, wide-beam or asymmetrical distribution, and provide for specific glare limitation characteristics. If the reflector contour is constructed by rotating a parabola or parabolic segment around its own axis, the result is a reflector with narrow-beam light distribution. In the case of linear light sources a similar effect is produced when rectangular reflectors with a parabolic cross section are used.

Reflector contours for parallel beam/parabola

Converging beam/ellipse

Diverging beam/hyperbola

Converging-diverging beam

In the case of parabolic reflectors, the light emitted by a light source located at the focal point of the parabola is radiated parallel to the parabolic axis. If there is a short distance between a parabolic reflector’s focal point and its apex, the reflector will act as a shield to direct rays. If this distance is large, then the direct rays will not be shielded. However, these can be shielded using a spherical reflector.

Wide-beam light distribution

If the reflector contour is constructed by rotating a parabolic segment around an axis, which is at an angle to the parabolic axis, the result is a reflector with wide-beam to batwing light distribution characteristics. Beam angles and cut-off angles can therefore basically be defined as required, which allows luminaires to be constructed to meet a wide range of light distribution and glare limitation requirements.
Parabolic reflectors can also be applied with linear or flat light sources, e.g. PAR lamps or fluorescent lamps, although these lamps are not located at the focal point of the parabola. In these cases, the aim is not so much to produce parallel directional light but optimum glare limitation. In this type of construction, the focal point of the parabola lies at the nadir of the opposite parabolic segments, with the result that no light from the light source located above the reflector can be emitted above the given cut-off angle. Such constructions are not only possible in luminaires, but can also be applied to daylight control systems; parabolic louvres, e.g. in skylights, direct the sunlight so that glare cannot arise above the cut-off angle.
**Darklight reflectors**

In the case of the conventional parabolic reflectors clearly defined light radiation – and effective glare limitation – is only possible for exact, point light sources. When using larger radiating sources, e.g. compact fluorescent lamps, glare will occur above the cut-off angle; glare is visible in the reflector, although the lamp itself is shielded. By using reflectors with a variable parabolic focal point (so-called darklight reflectors) this effect can be avoided; brightness will then only occur in the reflector of larger radiating sources below the cut-off angle, i.e. when the light source is visible.

**Spherical reflectors**

In the case of spherical reflectors the light emitted by a lamp located at the focal point of the sphere is reflected to this focal point. Spherical reflectors are used predominantly as an aid in conjunction with parabolic reflectors or lens systems. They direct the luminous flux forwards onto the parabolic reflector, so that it also functions in controlling the light, or to utilize the light radiated backwards by means of retro reflection back towards the lamp.

**Involute reflectors**

With involute reflectors the light that is emitted by the lamp is not reflected back to the light source, as is the case with spherical reflectors, but reflected past the lamp. Involute reflectors are mainly used with discharge lamps to avoid the lamps over-heating due to the retro-reflected light, which would result in a decrease in performance.
Double reflector systems consist of a primary and secondary reflector. The primary reflector aligns the light in a parallel or narrowly focused beam and directs it to the secondary reflector. The actual light distribution is created by the secondary reflector. The direct view of upon the high luminance of the lamp is prevented with double reflector systems, resulting in improved visual comfort. The precise alignment of the reflectors determines the efficiency of the system.

In the case of elliptical reflectors the light radiated by a lamp located at the first focal point of the ellipse is reflected to the second focal point. The second focal point of the ellipse can be used as an imaginary, secondary light source. Elliptical reflectors are used in recessed ceiling washlights to produce a light effect from the ceiling downwards. Elliptical reflectors are also ideal when the smallest possible ceiling opening is required for downlights. The second focal point will be an imaginary light source positioned at ceiling level; it is, however, also possible to control the light distribution and glare limitation by using an additional parabolic reflector.
Lenses are used almost exclusively for luminaires for point light sources. As a rule the optical system comprises a combination of one reflector with one or more lenses.

- Collecting lenses
- Fresnel lenses
- Sculpture lens
- Spread lens
- Flood lens
- Softec lens

Projecting systems
Collecting lenses

Collecting lenses direct the light emitted by a light source located in its focal point to a parallel beam of light. Collecting lenses are usually used in luminaire constructions together with a reflector. The reflector directs the overall luminous flux in beam direction, the lens is there to concentrate the light. The distance between the collecting lens and the light source is usually variable, so that the beam angles can be adjusted as required.

Fresnel lenses

Fresnel lenses consist of concentrically aligned ring-shaped lens segments. The optical effect of these lenses is comparable to the effect produced by conventional lenses of corresponding shape or curvature. Fresnel lenses are, however, considerably flatter, lighter and less expensive, which is why they are frequently used in luminaire construction in place of converging lenses. The optical performance of Fresnel lenses is confined by aberration in the regions between the segments; as a rule the rear side of the lenses is structured to mask visible irregularities in the light distribution and to ensure that the beam contours are soft.

Luminaires equipped with Fresnel lenses were originally mainly used for stage lighting but are now also used in architectural lighting schemes to allow individual adjustment of beam angles when the distance between luminaires and objects varies.

Sculpture lens

The sculpture lens produces asymmetrical light distribution. It spreads the beam of light in one axis, while leaving the light distribution unchanged on the other axis. The parallel ribbed lens produces a vertical oval when the ribs are orientated horizontally.

Spread lens

The spread lens is used with wallwashers. It produces asymmetrical light distribution. It spreads the beam of light in one axis, while leaving the light distribution unchanged on the other axis. The parallel ribbed lens produces a vertical oval when the ribs are orientated horizontally. This produces very even wallwashing.
The flood lens spreads the beam symmetrically. In addition, this textured lens gives softer transition at the beam edge.

The ability of the Softec lens results in a soft beam. This can be produced via a textured or frosted glass. Softec lenses are used to smooth out visible striations from reflector lamps. As a lamp cover, it prevents dazzle by reducing the lamp luminance.

In addition, different beam angles or image dimensions can be selected depending on the focal length of the lenses. In contrast to luminaires for Fresnel lenses it is possible to produce light beams with sharp contours; soft contours can be obtained by setting the projector out of focus.

Projector with optical system: a uniformly illuminated carrier (1) is focused via a lens system (2). The ellipsoidal projector (left) with high light output, and the condenser projector (right) for high quality definition.

Projecting systems comprise an elliptical reflector or a combination of spherical reflector and condenser to direct light at a carrier, which can be fitted with optical accessories. The light is then projected on the surface to be illuminated by the main lens in the luminaire. Image size and beam angle can be defined at carrier plane. Simple aperture plates or iris diaphragms can produce variously sized light beams, and contour masks can be used to create different contours on the light beam. With the aid of templates (gobos) it is possible to project logos or images.
Filters are optically effective elements which allow selective transmission. Only part of the incident beam is transmitted; consequently, either coloured light is produced or invisible beam components (ultraviolet, infrared) are filtered out. Filter effects can be attained using selective absorption or using interference. The filters’ permeability to light is known as transmittance.
Guide

Lighting technology | Luminaire technology

Filters

Types of filters

Absorption filters absorb certain spectral ranges and transmit the remaining radiation. The absorption process causes the filters to become hot. The separation of transmitted and reflected spectral components is not as exact as with interference filters and leads to a reduced edge steepness of the transmittance. Consequently, coloured glass filters create rather unsaturated colours. They have great longevity however.

Reflection filter

Interference filters (edge filters) are classed as reflection filters and give a high transmittance and an exact separation of transmitted and reflected spectral components. Glass filters coated with an interference coating can produce saturated colours. An accumulation of heat is avoided since reflection, and not absorption, takes place. The reflection spectrum is dependent on the angle of observation. Due to the vaporised coating, their scuff resistance is less than that of absorption filters.

Colour filters

Properties

Colour filters only transmit a certain part of the coloured, visible spectrum, whereby the remaining components of the radiation are filtered out. Colour filters made of plastic film are not heat resistant. Conversely, heat is not so critical for glass filters and, to an extent, they are resistant to temperature change. Absorption filters made of coloured glass attain lower colour saturation compared to interference filters. The colour-filtering property of interference colour filters is not immediately apparent – they do not look coloured.
In architectural lighting too, colours from the daylight spectrum are felt to be natural: Magenta (conditions of light at sunset), Amber (atmospheric light at sunrise), Night Blue (clear night sky) and Sky Blue (light of the sky by day). In scenic lighting, all colours of light come into play for highlighting and forming contrasts. In practice, when illuminating coloured surfaces, it is recommendable to perform lighting tests.

Corrective filters

Corrective filters designed as conversion filters will increase or reduce the colour temperature of the light source due to the spectral progression of the transmission. Skintone filters only correct the lamp’s light spectrum in the green and yellow spectral range and thereby produce a very natural and pleasant effect on skin tones. Daylight-conversion filters transform the warm white colour temperature in the range of the neutral white colour of light, i.e. from 3000K to 4000K.

Skintone filters are colour filters which improve the effect of natural warm colours, especially the colours of the skin. It is beneficial to use Skintone filters in communication areas, such as those of restaurants or cafes.

Conversion filters are used to adapt the warm white [light colour=1961] from halogen lamps to daylight lighting. Furthermore, by using daylight-conversion filters in warm white illuminated areas, it is also possible to create zones with neutral white light atmosphere.
Properties

UV filters are suitable for completely blocking ultraviolet radiation while allowing optimal transmission of visible light. The separation between reflection and transmission takes place at 400nm. The steeper the edge of the transmission curve, the less will be the colour distortion in the visible spectrum. UV filters are transparent (clear), the transmission is directional.

Infrared filters absorb or reflect the thermal radiation above 800nm while allowing optimal transmission of visible light spectrum. The thermal load on objects is reduced to a minimum. IR filters are transparent (clear), the transmission is directional. Adequate separation between lamp and filter avoids a build-up of heat within the luminaire.

Applications

Filtering out virtually all the ultraviolet radiation effectively delays the photochemical process of decay in textiles, watercolours, historic documents, artworks and other exhibits that are sensitive to light. This particularly applies to the bleaching of colours and to yellowing. In practice, since the UV component of high-pressure discharge lamps is already reduced by prescribed safety glasses, the highest ultraviolet loading is found from non-capsulated tungsten halogen lamps.

The use of infrared filters significantly reduces the thermal load and thus decreases the heat on an object or its surface. Materials sensitive to heat and humidity can thus be protected from drying out or distorting. High proportions of infrared radiation are emitted predominantly from light sources with low luminous efficacy, such as thermal radiators.

UV filters are suitable for use in:
- art museums
- art galleries
- natural-science museums
- antiquarian bookshops

IR filters are suitable for use in:
- art museums
- art galleries
- natural-science museums
- antiquarian bookshops
- food shops
Another means of controlling light optically is to deflect it using a prism. It is known that the deflection of a ray of light when it penetrates a prism is dependent on the angle of the prism. The deflection angle of the light can therefore be determined by the shape of the prism. If the light falls onto the side of the prism above a specific angle, it is not longer refracted but reflected. This principle is also frequently applied in prismatic systems to deflect light in angles beyond the widest angle of refraction and, in so doing, to cut out the light.

Prismatic systems are primarily used in luminaires that take fluorescent lamps to control the beam angle and to ensure adequate glare limitation. This means that the prisms have to be calculated for the respective angle of incidence and combined to form a lengthwise oriented louvre or shield which in turn forms the outer cover of the luminaire.

Typical light distribution of a fluorescent lamp with prismatic systems
Many luminaires can be equipped with accessories to change or modify their photometric qualities. Additional glare shields or honeycomb anti-dazzle screens can be used to improve glare limitation.
Anti-dazzle attachments

Barn doors allow the emitted beam to be separately restrained in each of the four directions and provide improved glare control. A cylindrical anti-dazzle attachment also restricts the view into the luminaire and reduces glare, but without the flexibility of barn doors. The anti-dazzle attachments are usually externally mounted on the light head. Glare limitation increases with the size of the anti-dazzle attachments. The black painted finish absorbs light and reduces the luminance contrasts.

Honeycomb anti-dazzle screen

The honeycomb anti-dazzle screen is used to control the beam and reduce glare. Honeycomb anti-dazzle screens are used where there are high demands for visual comfort in exhibition areas. Its limited depth means that the honeycomb anti-dazzle screen can be integrated within the luminaire. The black painted finish absorbs light and reduces the luminance contrasts.

Cross baffle

The cross baffle is used to reduce glare. Cross baffles are used where there are high demands for visual comfort in exhibition areas. The black painted finish absorbs light and reduces the luminance contrasts.
Framing attachment

A framing attachment allows various contours of the beam to be adjusted. Reflector-lens imaging systems make it possible to produce a sharp-edged beam. However, a blurred projection results in a soft-edged beam. The separately adjustable sliding components can, for example, be used to create rectangles on walls in order to highlight objects crisply around their contours.

Applications:
Museo Deu, El Vendrell
Museo Ruiz de Luna Talavera, Toledo
Goya exhibition, Madrid

Gobo

The term “gobo” refers to an aperture plate or image template through which light is projected by an imaging projector. Gobos make it possible to project lettering or images. Reflector-lens imaging systems can be used to create crisp images or even soft-edged transitions using blurred projections.

Applications:
Teatri Ravintola, Finland
Aragon Pavilion, Seville
ERCO, Lüdenscheid
The incorporation of coloured light opens up interesting possibilities for influencing the atmosphere of rooms. Under electronic control, a large number of colours can be generated and a smooth colour changes produced in the luminaire.
Introduction

The addition of the name ‘varychrome’ to ERCO luminaires identifies those luminaires whose colour can be changed dynamically. These luminaires are electronically controlled to generate variable light colours by additive colour mixing of the primary colours red, green and blue (RGB technology). They enable an infinitely variable adjustment of different light colours.

The advantages of colour mixing using coloured lamps are that complex mechanical components are not needed and colour filters with low transmission are avoided. The term 'varychrome' refers to the mixing of colours. It is derived from the Latin adjective ‘varius’ meaning different and the Greek word ‘chroma’ for colour.

Technology

In principle, the colours of the fluorescent lamps can be chosen at will. A multitude of colours can be mixed from the coloured fluorescent lamps in red, green and blue. The saturation and the chromaticity location of the lamps determine the size and shape of the resulting colour triangle. The lamps in warm white, neutral white and daylight white can create various different white light colours. The fluorescent lamps primarily produce diffuse light with low brilliance.

The luminaires with LEDs feature a high colour density, which therefore results in a large colour triangles. Characteristic for LEDs are low luminous flux, compact dimensions and long service life.
Light simulation and light calculation have become essential components of lighting design. They enable the creative design of lighting solutions on the computer and range from the evaluation of experimental concepts to photorealistic presentations. The calculation methods are used for quantitative analyses to verify the required illuminances. However, to ensure efficient use of this technology, knowledge of the underlying technical principles is necessary.
Architects and lighting designers use different methods to convey ideas and technical details and communicate these to those involved in the planning process. Concepts can be visually compared during the design phase in order for decisions to be made prior to construction. Since the 80s the established methods of sketching, model making, sampling and drawings have been extended by techniques of digital simulation.
Evaluation and presentation

Comparable to model making, the simulation also differentiates between the working model and the presentation model. While the working model simplifies the design process in that it provides rough, sketched variants, the presentation model includes elaborate details. In lighting design, sketches, digital drawings and photo realistic representations are quick visualisation methods. For further examination this is followed by general light simulation, omitting exact details of materials or luminaires. In a subsequent step, the simulation is improved by including realistic surfaces and specific luminaires with accurate photometrics for detailed planning and presentation purposes.

Simulation and image processing

Simulation is generally associated with 3D models and an accurate representation of the lighting effect. However, for schematic visualisations, designers often use digital image processing in a 2D or 3D representation. The advantage lies in the speed of abstraction and realisation. If the space to be illuminated is complex then this method does not allow detailed planning due to limitations associated with scaling and complicated geometry.

Quantitative and qualitative simulation

In lighting design, simulation includes two aspects. The quantitative simulation provides physically correct, numerical values to verify the illuminances and lamp luminances specified. The qualitative simulation, on the other hand, focuses on atmosphere and is used by lighting designers to communicate their aesthetic idea of the lighting design.
Simulation and reality

Often, the quality of a simulation is judged by its proximity to reality and the question is asked as to whether the rendering is correct or no more than a photorealistic representation. The criterion of physically correct data refers to the numerical values provided by the quantitative simulation. Screen displays or colour printouts can never give the same impression as the actual environment. A photographer controls the incident light by opening or closing the aperture and the same creative approach is taken in the production of a rendering. A further limitation is the range of contrasts on the output media. None of the following can correctly reproduce the luminance contrast which will be seen in reality: colour printout, screen display or the projected image of a beamer. A photorealistic impression of a qualitative simulation can provide a far more authentic representation of the anticipated lighting effect, such as the progression of light and shadow or reflections off surfaces.

Interaction

To visualise changes instantly during the processing stage, designers prefer an interactive simulation. Based on the current state of the art, however, the interaction is limited by the available programs and significantly depends on the hardware. Interactive aspects in the programs usually include changes to the geometry, camera position, texture and simple modifications of the light sources and material properties. Currently changes to reflections, complex shadows and indirect light are excluded.
A crucial factor in ensuring an efficient light simulation during the design process is a reasonable degree of detailing and the assistance of an expert. Time and cost can be controlled by limiting the scope of the presentation. The implementation of the light simulation can either be handled by the design office itself or outsourced to a specialist provider. If handled internally, a rendering can be prepared in conjunction with the design process. Simulations, on the other hand, using an external service provider involve considerable information exchange. This is compensated for by the fact that the service provider has greater experience, can produce quicker results and this can lead to reducing the cost for the design.

The sequence of a light simulation can be divided into four steps: the modelling of the geometry, the definition of materials, the illumination of the model, and the actual rendering process.
The light simulation has proven to be a useful tool in the visualisation and verification of the lighting design. Initially, a number of steps are required for the preliminary planning of the rendering: the concept idea and the sketch, the 3D CAD model and the specification of the light sources and surface properties. For professional light simulations, the designer uses specialised software such as 3ds VIZ/Max or DIALux. Most CAD programs are not able to simulate light with physically accuracy.
A simulation is based on the 3D data of a room which is used to produce images. This 3D data can be imported from simple CAD programs or specialised applications. If the design office already works with 3D data, they can be imported into the light simulation software. The more sophisticated the 3D model, the more realistic the light simulation will be, but also of course the more time-consuming.
Export and import

Where a 3D model exists in a program other than the one used for light simulation, the data can be transferred using the export and import functions. Since 3D models contain complex data, the designer must consider sources of error and allow for manual corrections. It is advisable to export the data simultaneously in several established exchange formats. These 3D CAD exchange formats include DWG, DXF, and 3DS.

Topology

CAD programs increasingly work with component-orientated functions such as the generation of pillars or ceilings. Often, however, it remains unclear as to whether the elements are made up of surfaces or volumes. In the simulation programs, though, the designer is confronted with the basic 3D elements without component details; these can be vertex, edge, face/polygon and surface normal: the vertex with the X, Y and Z coordinates, an edge is defined by two vertices and a surface by three. The normal is positioned vertically on the surface and reveals its front face. After exporting from a component-orientated CAD program, the designer needs to be prepared eventually for a different structure where modifications of the geometry are made in the simulation program.
Since CAD models can be used for other requirements than light simulation, the geometry model frequently causes problems in the simulation. While the wire cables of a banister can easily be designed as high-resolution cylinders in a CAD program, the calculation of the cylinder surface is complicated to render. The designer must take this into account as early as possible in the preparation of the 3D model in order to review the export settings. Since simulations require extensive calculations and will continue to do so, an optimised geometry considerably reduces the work and time involved in producing light simulations. Small, highly detailed geometries on a separate, inactive layer can reduce the calculation time. Similarly, it is advisable to use a material-based layer structure for quick provisional calculations.
Materials are recognised solely through definition of the surface properties. Depending on the complexity required, the simulation programs allow for anything between simple and complex settings.
Shading

The term "shading" refers to the representation of shades. The designer uses a shader to define the lighting properties through the colour, the reflectance and the transparency. These determine how the light will appear on an object and affect the surroundings. The lighting effect of the material properties always depends on the type and position of the light sources and is visible only in the combination of shading factors and lighting: hence, shiny spots on reflecting surfaces appear only when the light from the light sources shines directly onto these surfaces.

Texture

To show objects which don't have a uniform surface colour, the surface can be given a texture. This method, known as "mapping", places abstract, graphical patterns or photos on the model. Simulation programs provide extensive material collections in libraries to enable designers to show textures such as wood or exposed concrete. Using special mapping methods (bump mapping), microstructures can be modified so as to give the impression of three-dimensional surfaces. A highly realistic impression results if by photos are assigned as textures to polygons. To ensure acceptable quality, the photo should be high resolution, be taken head-on and contain no light or other reflections. It must also be without distortions due to the lens.
Where the atmosphere of a room is to be shown realistically, light is one of the key factors in the visualisation. It is essential in the perception of the environment and determines how rooms and objects are interpreted. Simulating light using a rendering in a 3D model is a time-consuming process. To do so, the designer can resort to standardised light sources or work with digital data records to reproduce specific luminaires.
Direct light

Direct light refers to rays of light shining directly onto the surface. If there is no obstruction then a point on the surface is illuminated. The calculation of direct light requires minimum time and has been possible from the early days of computer graphics. This has one significant limitation in that indirect light is not included: hence, a room illuminated using only ceiling washlights would be completely dark, except for the areas where the ceiling is illuminated by the direct light.

Indirect light

Indirect light is produced as a result of light reflecting off a surface. The reflectance of the surface and the degree of diffusion which is often assumed, determines the calculated, reflected indirect light. To create an accurate impression of the room, designers need to calculate as many interreflections as possible to achieve a representational light distribution in the room. It was not until the 1990s that progress in hardware allowed such a complex calculation. The calculation of indirect light is also known as “global illumination”.

Simulation programs include general light sources such as spot, point, area and sunlight. The representation of special luminaires, however, requires an interface that can import the light distribution data from the luminaires. These data records are available from most luminaire manufacturers and describe the specific light intensity distribution of each luminaire. The IES format is a common international data format. Luminaires with an asymmetric light distribution, for example, cannot be calculated correctly in any other way. The use of accessories such as a sculpture lens affects the light distribution and requires a separate data record.

Rather than being limited to a quantitative light simulation, if the designer also wants to demonstrate the effect of luminaires in the room, the luminaires must be available as 3D models. To do this some luminaire manufacturers provide what are called virtual luminaires, which include the 3D geometry of the luminaire, the surface properties, the functional rotation axis and the light intensity distribution. Using inverse kinematics, spotlights can be set up quickly and realistically: if the designer adjusts the light distribution in the room, the movable parts of the luminaires automatically follow.

The combination of daylight with direct sunlight and the diffuse sky light, gives simulations the impression of reality. While the calculation of daylight for presentations and shading studies is easy, quantitative representation is difficult. Accurate information on glare control at workplaces and on heat transmission for different types of sun protection glazing can only be obtained using special software with appropriate analysis tools.
A render engine is an application that allows photorealistic images to be generated from a 3D model. Every simulation program has special rendering procedures, each of which has advantages and disadvantages. Experience has shown that every three or four years, the progress made in hardware performance allows new methods of calculation. Despite the improvements in simulation programs, the quality of the renderings still ultimately depends on the skill of the designer.
Radiosity

In calculations of light distribution using the radiosity process the rays are emitted by the light source and are reflected back by a surface. This process continues with a defined number of iterations and consequently also takes into consideration the light reflecting off other surfaces. A key advantage of radiosity is the storage of light properties in a grid on the model geometry. In this way, the camera angle can subsequently be changed without requiring a revised calculation. The disadvantage of radiosity is the effect on the calculation time of details, spheres or complex scenes with a very large number of polygons. A relatively coarse grid of values for quicker calculation, on the other hand, can lead to errors in the light intensity distribution.

Photon mapping

Photon mapping is similar to the ray tracing process. While ray tracing is based on rays from the observers/camera position, photon mapping is based on rays emitted from the light source. Photon mapping uses virtual “photons” radiating light into the room. When they hit a surface, they are reflected back and the luminance values are summed. The photon outputs are stored in a photon map. This map is not bound to the geometry and can be used for simulations with distributed calculations in the network. The camera position can be modified without the need to revise the calculation – this process, though, is not interactive. The more photons a model has, the more accurate the transitions will be in the rendering and the more complex the calculation. After a certain number of reflections/iterations, the photon map has the required precision. In a further process, the points can be merged through gathering. Photon mapping is used as for further calculations. To show details more accurately, the process is combined with ray tracing. If the calculation is based exclusively on ray tracing it is too complex for very small models and very bright light sources.
Ray tracing
(Backward) ray tracing, also called Monte Carlo ray tracing, is the second of the two most popular processes used for the calculation of light distribution. Unlike radiosity and photon mapping, however, it does not trace a ray of light from the light source. Instead, the rays start from the eye and are followed backwards to the model and the light sources. If the rays from the eye hit a surface, other rays of light are used to see whether this point reflects light or contains shadows. The result is shown as pixels on a focal plane. The higher the resolution required on the focal plane and the more reflecting surfaces there are, the more rays of light are required for the simulation and the more complex the calculation becomes. Ray tracing has the advantage of producing exact representations of details and the smallest shadows. Since this method depends on the focal plane, a change of angle and the line of vision requires a new calculation. Scenes with very high contrast ratios are difficult to represent, as the incidental rays of light for calculation start from the observer/camera position and light apertures such as small windows in a large wall can initially be disregarded.
In the same manner as photos can be evaluated based on technical quality criteria, designers can check renderings for errors. Where the first impression often determines the general aesthetic appearance and the similarity of the lighting effect to the natural environment, there are various criteria for a critical technical evaluation. The desire for maximum precision in a visualisation has to be balanced with the complexity of detailed modelling and the time-consuming calculation. So, designers need to find a reasonable compromise between precision and speed for the simulation.
The image design is assessed, focusing on aesthetic aspects. The perspective - whether with isometry or a central or two-point perspective - determines the geometric or natural impression. In the same manner, the overall brightness, contrast and colour density contribute to a realistic representation. Carefully defined surfaces create a realistic impression.
Correct settings for the calculation of illuminance of objects can be seen by the details of the objects. Curved edges that show aliasing effects such as sharp edges or hard transitions require less computing power. Often, the calculation times can be reduced many times over if only a few sample points are smoothed and gathered. While this shortcut is not visible on smooth surfaces, the error will be visible on small, complex forms. This aspect is relevant where details have high luminance contrasts. This is similar to the luminance progression on component edges or the weak shadow of an object due to excessive interpolation of the shadow-effect in the room.

If the grid is too coarse and the components are not accurately connected, the light distribution can be wrong, resulting, for example, in light apparently shining through a wall or a ceiling.
The effects of faster hardware on the computing power are more obvious in light simulation than in other areas of application, including communication or word processing. To ensure an efficient simulation process, it is crucial to establish a harmonic balance between the processor, the memory and the graphics card.
**Processor**

The processor (CPU, Central Processing Unit) is responsible for the computing power. A processor working twice as fast as others reduces the calculation time for a rendering by half. Today the use of dual processors is recommended. Some workstations have several CPUs instead. For complex tasks, the designer can include other computers in the network for distributed calculations.

**Main memory**

The main memory (RAM, Random Access Memory) does not directly affect the computing speed. In the first instance, it determines how big the edited scene can be, before the computer writes data onto the hard drive. This writing process is tedious and slows down the rendering process. Since the dependence here is not linear, the performance drops significantly once a certain threshold is reached. If the calculation frequently coincides with hard drive activity, it is advisable to increase the main memory.

**Graphics card**

The graphics card determines the degree of possible interactivity with the 3D model, specifically in case of textured objects. The actual computing speed is hardly affected by the graphics card. Some developments, however, show that the graphics card will, in future, also be used for simulations.
There is a wide range of programs available for light simulation. The software spectrum covers everything from fast, quantitative analyses to sophisticated visualisation methods. Whether a software package can produce accurate light simulations is indicated in the manual, which must specify support of global illumination or radiosity and the IES or Eulumdat format. If it does then the designer can combine the photometric data with the respective 3D DXF data.
DIALux is a free of charge lighting design software application for calculation and visualisation. The program is provided by the Deutsches Institut für Angewandte Lichttechnik (DIAL – German Institute of Applied Lighting Technology). The DIALux software gives a quick and easy quantitative analysis of a design and includes simple 3D and rendering functions. The ULD data format for the luminaires comprises the 3D geometry of the luminaire, the light intensity distribution, and an article description. The plug-in packages of luminaire manufacturers contain additional planning data such as maintenance factors or UGR values.

For further information on the DIALux software visit www.dialux.com.

Autodesk

One of the products available from Autodesk is the VIZ software, a program for sophisticated visualisations. The luminaire data for Autodesk VIZ and also for 3ds Max include a 3D model of the luminaire. This includes surface properties, textures and the possible motion of components (inverse kinematics). Inverse kinematics allows directional luminaires to be aligned through a few simple adjustments. A light simulation requires additional photometric data. Autodesk VIZ and 3ds Max enable radiosity calculations to produce numerically accurate light simulations.

Radiance

Radiance is a professional light simulation program from Berkeley Lab. Its wide range of calculation and analysis tools requires extensive knowledge of operating systems and shell commands and consequently, it is mostly used in research institutes and by highly specialised companies. Due to its complexity, the program is not suitable for quick representations of qualitative lighting designs. A physically correct light simulation is possible with IES luminaire data.
Compared with other technologies such as digital photography or desktop publishing, the 3D visualisation method is far from being fully developed. Within a few years, innovations can significantly change the processes. A number of developments in light simulation are expected in the near future.
HDR
The acronym HDR stands for “High Dynamic Range” and describes a technical format that stores and displays a higher luminance contrast. Today’s graphical output devices largely work with a “Low Dynamic Range” with 255 tones per colour channel for RGB (8bit). In a scene with a very high luminance contrast, as may be caused by the sun, for example, some areas can be 100,000 times brighter than shaded areas. If the image is saved as a TIFF or jpg file, the contrast range is compressed such that the sun is only 255 times brighter than the shadow. The sun and a white vase can both be white in an image and thus fail to reproduce the luminance contrast correctly. Because the full range of contrast levels is maintained in HDR format images (32bit), new possibilities arise for a subsequent exposure or for renderings. Where this is common practice already, the development of HDR-compatible monitors will raise this technology to even higher levels. In the medium term, the HDR format will replace the current image formats. The RAW photo format is already a step in this direction.

Light spectrum
In most simulation modules, the quality of the colour rendition cannot yet be reproduced because the appropriate data and programs are not available. Rather than calculating the entire visible spectrum of light, the software currently only calculates certain segments: red, green and blue. Since the various types of lamp do not have a uniform spectrum, the result is different colour renditions that are not covered by the simulation programs. Consequently, specifics on the colour rendition of illuminated textiles in a shop, for example, are not possible with the current state of the art. Appropriate future functions would additionally require the definition of the spectral characteristics of both the light sources and the surfaces.

Real-time rendering
Simulations always result in some time delay between input and result. Consequently real-time calculations would be ideal. Many functions can already be performed in real time. Often, however, the technical progress also involves higher representation requirements, which results in speed reduction. The real-time technology is inspired by computer games, where interaction directly modifies the image sequence. Computer game users benefit from elaborate preliminary calculations that are uncommon in architectural simulations. The solutions developed by the manufacturers of rendering programs depend on the hardware functions of powerful graphics cards.
The planning and design of lighting installations involves a number of technical and economical calculations. Usually, these relate to the average lighting level or the exact illuminance at individual points in the room. In addition, it may be useful to determine the luminance levels in specific areas of the room, the quality features of the lighting such as shadow effects and contrast rendition or the cost of a lighting installation including maintenance cost.
When planning the connected load, the specific luminaire and light source used is taken into consideration to determine the load, or the number of luminaires, required to achieve the specified illuminance. Alternatively, the specified connected load and light source can be used to calculate the average illuminance. The connected load is used in the planning of regular luminaire grids. To estimate the approximate lighting levels, luminaire manufacturers provide tables indicating the illuminances of specified numbers of luminaires.
Number of luminaires

Specifications
Connected load of one luminaire
P: 66.0 W
Connected load per 100lx
P*: 2.81 W/m²
Em: Maintained value of illuminance
DIN EN 12464
f: Correction factor from separate correction table 0.93
MF: Maintenance factor, reference value 0.80

Example with P*
\[
E_m = \frac{n \cdot a \cdot b \cdot P^*}{P \cdot f \cdot MF}
\]
\[
500lx \cdot 12m \cdot 14m \cdot 2.81W/m^2
\]
\[
66W \cdot 0.93 \cdot 0.81 \cdot 100lx
\]
\[
n = 48
\]

The required number of luminaires for a specific illuminance can be calculated on the basis of the connected load values given for a luminaire and 100lx. A further parameter to be included is the maintenance factor to ensure the required illuminance over the entire period of operation. Since the values only apply to a standard room, the calculation for other conditions requires a correction factor.

Guide
Simulation and calculation | Calculations
Connected load

Illuminance

Specifications
22227.000
Connected load of one luminaire
P: 66.0 W
Connected load per 100lx
P*: 2.81 W/m²
Em: Maintained value of illuminance
DIN EN 12464
f: Correction factor from separate correction table 0.93
MF: Maintenance factor, reference value 0.80

Example with P*
\[
E_m = \frac{n \cdot P \cdot f \cdot MF}{a \cdot b \cdot P^*}
\]
\[
48 \cdot 66W \cdot 0.93 \cdot 0.80 \cdot 100lx
\]
\[
12m \cdot 14m \cdot 2.81W/m^2
\]
\[
E_m = 499
\]

In order to calculate the illuminance of a specified number of luminaires, the designer requires information on the connected load per luminaire per 100lx. The maintained level of illuminance is determined using the maintenance factor. The maintained value is the minimum illuminance level that must be maintained during the operation of the lighting installation. Since these values only apply to a standard room, the calculation for other conditions requires a correction factor.
The illuminance distribution at certain points in the room can be calculated using the inverse square law. This is based on the fact that the illuminance reduces with the square of the distance from the light source. Indirect lighting components are not included in this calculation. Point illuminances can be calculated for a single luminaire or several luminaires. For confined areas with individual luminaires, manual calculations can be appropriate. Where there are a number of luminaires and functional areas in a room, designers use lighting design programs that then include the indirect lighting components. The programs can determine the illuminance for all room surfaces and working planes. The results are displayed in graphic representations of Isolux charts or false colour diagrams.

$$E_h = \frac{1}{h^2}$$
To ensure that the required illumination is provided over a period of time, the lighting design includes a maintenance factor $MF$ that takes into account the reduction of luminous flux. The new value for the illuminance of an installation is calculated from the maintained value of illuminance, and the maintenance factor. The maintenance plan specifies the cleaning frequency of the luminaires and the room and the lamp replacement. The maintained value of illuminance thus depends on the luminaires, the lamps and the room conditions.

<table>
<thead>
<tr>
<th>Luminaire Maintenance Factor</th>
<th>Room Surface Maintenance Factor</th>
<th>Lamp Lumen Maintenance Factor</th>
<th>Lamp Survival Factor</th>
</tr>
</thead>
</table>
### Luminaire Maintenance Factor

**Cleaning frequency (a)**

**Environmental conditions**
- A Open luminaires
- B Open-top reflectors
- C Closed-top reflectors
- D Closed reflectors
- E Dustproof luminaires
- F Luminaires with indirect emission

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<th>9</th>
<th>10</th>
<th>11</th>
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<tbody>
<tr>
<td>P</td>
<td>0.96</td>
<td>0.93</td>
<td>0.89</td>
<td>0.84</td>
<td>0.78</td>
<td>0.91</td>
<td>0.85</td>
<td>0.79</td>
<td>0.73</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>0.96</td>
<td>0.90</td>
<td>0.86</td>
<td>0.80</td>
<td>0.75</td>
<td>0.84</td>
<td>0.79</td>
<td>0.74</td>
<td>0.68</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>N</td>
<td>0.94</td>
<td>0.89</td>
<td>0.81</td>
<td>0.72</td>
<td>0.69</td>
<td>0.59</td>
<td>0.84</td>
<td>0.74</td>
<td>0.61</td>
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<tr>
<td>D</td>
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<td>0.88</td>
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<td>0.77</td>
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</tr>
<tr>
<td>P</td>
<td>0.98</td>
<td>0.94</td>
<td>0.90</td>
<td>0.86</td>
<td>0.81</td>
<td>0.94</td>
<td>0.90</td>
<td>0.84</td>
<td>0.79</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>0.91</td>
<td>0.86</td>
<td>0.81</td>
<td>0.74</td>
<td>0.66</td>
<td>0.80</td>
<td>0.70</td>
<td>0.55</td>
<td>0.45</td>
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</tr>
</tbody>
</table>

### Room Surface Maintenance Factor

**Cleaning frequency (a)**

**Environmental conditions**
- Direct emission
- Direct/indirect emission
- Indirect emission

**Classification of Environmental Conditions**
- P (very clean room) pure
- C (clean room) clean
- N (average conditions) normal
- D (dirty room) dirty

<table>
<thead>
<tr>
<th></th>
<th>1</th>
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<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>0.99</td>
<td>0.98</td>
<td>0.96</td>
<td>0.95</td>
<td>0.97</td>
<td>0.96</td>
<td>0.95</td>
<td>0.94</td>
<td>0.91</td>
<td>0.86</td>
<td>0.82</td>
<td>0.78</td>
</tr>
<tr>
<td>C</td>
<td>0.96</td>
<td>0.92</td>
<td>0.88</td>
<td>0.85</td>
<td>0.93</td>
<td>0.89</td>
<td>0.85</td>
<td>0.81</td>
<td>0.90</td>
<td>0.86</td>
<td>0.82</td>
<td>0.78</td>
</tr>
<tr>
<td>N</td>
<td>0.94</td>
<td>0.88</td>
<td>0.82</td>
<td>0.77</td>
<td>0.91</td>
<td>0.84</td>
<td>0.77</td>
<td>0.70</td>
<td>0.84</td>
<td>0.78</td>
<td>0.72</td>
<td>0.64</td>
</tr>
</tbody>
</table>

The luminaire maintenance factor LMF takes into account the reduction of luminous flux due to the soiling of the luminaire. It signifies the ratio of a luminaire’s light output ratios before and after cleaning. The LMF depends on the shape of the luminaire and the related possibility of soiling. The LMF classification is indicated next to the product. At this point, the optimal cleaning frequency must be defined for the maintenance plan.

The room surface maintenance factor RSMF takes into account the reduction of luminous flux due to the soiling of the room surfaces. It signifies the ratio of the room surface reflectances before and after cleaning. The RSMF depends on the degree of soiling of the room or the ambient conditions of a room and the specified cleaning frequency. Further influencing factors are the size of the room and the type of lighting (direct to indirect emission). The room surface maintenance factor consists of four classifications for room surface deterioration: P pure (very clean room), C clean (clean room), N normal (average conditions) and D dirty (dirty room).
**Guide**

Simulation and calculation | Calculations

**Maintenance Factor**

**Lamp Lumen Maintenance Factor**

<table>
<thead>
<tr>
<th>Hours of operation (h)</th>
<th>2000</th>
<th>4000</th>
<th>6000</th>
<th>8000</th>
<th>10000</th>
<th>12000</th>
<th>14000</th>
<th>16000</th>
<th>18000</th>
<th>20000</th>
</tr>
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<tbody>
<tr>
<td>Tungsten halogen lamps/low-voltage</td>
<td>0.95</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Metal halide lamps</td>
<td>0.86</td>
<td>0.82</td>
<td>0.75</td>
<td>0.69</td>
<td>0.66</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>High-pressure sodium vapour lamps</td>
<td>0.99</td>
<td>0.98</td>
<td>0.97</td>
<td>0.97</td>
<td>0.96</td>
<td>0.96</td>
<td>0.95</td>
<td>0.95</td>
<td>0.94</td>
<td>--</td>
</tr>
<tr>
<td>Compact fluorescent lamps</td>
<td>0.92</td>
<td>0.88</td>
<td>0.85</td>
<td>0.83</td>
<td>0.83</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Fluorescent lamps</td>
<td>0.96</td>
<td>0.95</td>
<td>0.94</td>
<td>0.93</td>
<td>0.92</td>
<td>0.91</td>
<td>0.90</td>
<td>0.89</td>
<td>0.88</td>
<td>0.88</td>
</tr>
</tbody>
</table>

The lamp lumen maintenance factor LLMF takes into account the reduction of luminous flux due to the ageing of the lamp. It signifies the ratio of the lamp lumens at a specific time and the new value. The current data provided by the lamp manufacturers must be taken into account here.

**Lamp Survival Factor**

The lamp survival factor LSF takes into account the variation of the life of individual lamps from the mean life of the lamps. The LSF depends on the service life of the lamp. The latest data provided by the lamp manufacturers must be taken into account here. If defective lamps are replaced immediately, the lamp survival factor applied is LSF = 1. The maintenance plan for a lighting installation must also specify the optimal lamp replacement frequency. This depends on the degree of use of the lamp and is determined by analysing the period of illumination and the mean service life of the specific lamps.
The UGR method (Unified Glare Rating) is an international index presented by CIE in publication 117 and is used to evaluate and limit the psychological direct glare from luminaires. Unlike previous methods where the glare was rated using the luminaire values of a single luminaire, this method calculates the glare of the entire lighting installation at a defined observer position. According to DIN EN 12464, the UGR value is provided for a standard room. An exact calculation of the UGR value at a defined observer position in a room is possible with modern lighting design programs. The lower the UGR value, the lower the glare. Where the luminaire is < 1000 cd/m², additional data is provided on the elevation angle, either 65°, 75° or 85°. This is the critical angle above which the luminaire has an all-round luminance of 1000 cd/m².

Utilisation factor method

\[ n = \frac{1}{V} \cdot \frac{E_n \cdot a \cdot b}{\Phi \cdot n_r \cdot n_l b} \]

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( E_n )</td>
<td>Nominal illuminance</td>
</tr>
<tr>
<td>( n )</td>
<td>Number of luminaires</td>
</tr>
<tr>
<td>( a )</td>
<td>Length of space (m)</td>
</tr>
<tr>
<td>( b )</td>
<td>Width of space (m)</td>
</tr>
<tr>
<td>( \Phi )</td>
<td>Luminous flux per luminaire (lm)</td>
</tr>
<tr>
<td>( n_r )</td>
<td>Utilance</td>
</tr>
<tr>
<td>( n_l b )</td>
<td>Light output ratio</td>
</tr>
<tr>
<td>( V )</td>
<td>Light loss factor</td>
</tr>
</tbody>
</table>

Utilisation factor method: formula for calculating the nominal illuminance \( E_N \) for a given number of luminaires or the number of luminaires \( n \) for a given illuminance. The utilisation factor method is used for an estimated calculation of lighting installations. It is used to calculate the number of luminaires required for the target illuminance on the working plane or the illuminance achieved by a specified number of luminaires. The utilisation factor method is based on the fact that the average horizontal illuminance for a room of a specific size can be calculated using the total luminous flux of the installed luminaires and the light output ratio along with the utilisation factor. The utilisation factor method is rarely relevant to routine planning any more since it is based on standardised rooms. Today, it is much easier and quicker to calculate individual rooms using computer programs. The utilisation factor method is still used as the basis for the relevant European standard and for planning programs, to calculate the average illuminance for rooms on regular luminaire grids.
### 3.3.6.4 Lighting costs

The cost of a lighting installation is divided into fixed and flexible costs. The fixed costs are unrelated to the operating time of the lighting installation and comprise the annual costs for the luminaires, their installation and their cleaning. The flexible costs, on the other hand, depend on the operating time and include the electricity costs and the material and labour costs for lamp replacement. These values form the basis for the calculation of a number of features of the lighting installation. Of particular interest here are the costs accruing annually for a lighting installation. Often, however, it also makes sense in the planning phase to compare different types of lamps in terms of their efficiency. Again, these can be calculated as annual costs or as costs for the production of a specific quantity of light. When planning a new installation and specifically when improving an existing, lighting installation, it is helpful to calculate the pay-back time, i.e. the period required for the operating costs savings to offset the investment costs of the new installation.

#### Lighting costs

\[
K = K' + K''
\]

\[
K' = n \left( p \cdot K_1 + R \right)
\]

\[
K'' = n \cdot t_a \left( a \cdot P + \frac{K_2}{t_a} \right)
\]

\[
K = n \left[ p \cdot K_1 + R + t_b \left( a \cdot P + \frac{K_2}{t_a} \right) \right]
\]

\[
t = \frac{K_i \text{(new)}}{K'' \text{(old)} - K'' 	ext{(new)}}
\]

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>a (EU/kWh)</td>
<td>Energy costs</td>
</tr>
<tr>
<td>K (EU/a)</td>
<td>Annual costs for a lighting installation</td>
</tr>
<tr>
<td>K' (EU/a)</td>
<td>Fixed annual costs</td>
</tr>
<tr>
<td>K (EU/a)</td>
<td>Annual operating costs</td>
</tr>
<tr>
<td>K_i (EU)</td>
<td>Costs per luminaire incl. mounting</td>
</tr>
<tr>
<td>K_2 (EU)</td>
<td>Costs per lamp incl. lamp replacement</td>
</tr>
<tr>
<td>K_i (EU)</td>
<td>Investment costs (n·K_i)</td>
</tr>
<tr>
<td>n</td>
<td>Number of luminaires</td>
</tr>
<tr>
<td>p [1/a]</td>
<td>Interest payments for the installation [0.1–0.15]</td>
</tr>
<tr>
<td>P (kW)</td>
<td>Wattage per luminaire</td>
</tr>
<tr>
<td>R (EU/a)</td>
<td>Annual cleaning costs per luminaire</td>
</tr>
<tr>
<td>t (a)</td>
<td>Pay-back time</td>
</tr>
<tr>
<td>t_a (h)</td>
<td>Annual operating time</td>
</tr>
<tr>
<td>t_s (h)</td>
<td>Service life of a lamp</td>
</tr>
</tbody>
</table>
The lighting design process requires detailed information to ensure compliance with the standards relating to illuminances and visual comfort. Thus for the simulation programs, luminaire manufacturers provide files that contain data on the lighting technology of the luminaires.
For the light simulation, designers use data on three-dimensional light intensity distribution and geometry to determine the illuminances and the luminance levels. They also use them to evaluate the visual impression of a luminaire in the room.
IES / Eulumdat

The IES data format is an internationally accepted data format used to describe the light distribution of luminaires. It can be used in numerous lighting design, calculation and simulation programs. Originally, the format was the standard of the IESNA (Illuminating Engineering Society of North America). The current version is IES LM-63-02. Eulumdat is the European lumen data format as the equivalent of the IES.

DXF

The DXF format stores the geometry of a luminaire; the materials and light distribution are not saved in this exchange format. This data format can be imported into most CAD systems. DXF data with 2D elements are used in the planning process to enter the luminaires on the ceiling plan. DXF data with 3D elements give an accurate impression of the luminaires in spatial representations.

i-drop

i-drop is a technology provided by the software manufacturer Autodesk. Using the "drag & drop" function, it enables contents to be imported from the Internet into the software application. For the light simulation, virtual luminaires can be downloaded with the relevant photometric data directly from the website of the luminaire manufacturer and included in the simulation program. The data comprise the 3D geometry, photometry and textures. A luminaire can be "dropped" directly into the required position in the light simulation scene. To align the luminaire automatically with the room surfaces or any surface normal, the "autogrid" function needs to have been previously activated. Using inverse kinematics, the luminaire is aligned with the target of the light source. i-drop works with programs including VIZ 4 VIZrender, 3ds Max 5 and 6, AutoCAD, and DIALux. System requirement is the Microsoft Internet Explorer and activation of the Active X functions.
The maintained value of a lighting installation is calculated using the light output ratio and the luminaire maintenance factor specified for the luminaire.
According to DIN/EN 13032/2, the LOR (Light Output Ratio) describes the ratio of the luminous flux of the luminaire to the lumens of the lamps used. Luminaires with direct/indirect emission also specify the "DLOR" (Downward Light Output Ratio) and the "ULOR" (Upward Light Output Ratio) as separate components. These indicate the light intensity distribution of a luminaire in the lower and upper parts of the room.

Luminaire Maintenance Factor

Cleaning frequency (a)

<table>
<thead>
<tr>
<th>Environmental conditions</th>
<th>P</th>
<th>C</th>
<th>N</th>
<th>D</th>
<th>P</th>
<th>C</th>
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<th>P</th>
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</thead>
<tbody>
<tr>
<td>A Open luminaires</td>
<td>0.96</td>
<td>0.96</td>
<td>0.96</td>
<td>0.96</td>
<td>0.93</td>
<td>0.93</td>
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<td>0.91</td>
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</tr>
<tr>
<td>B Open-top reflectors</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
<td>0.89</td>
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<tr>
<td>C Closed-top reflectors</td>
<td>0.94</td>
<td>0.94</td>
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<tr>
<td>E Dustproof luminaires</td>
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<td>0.79</td>
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<tr>
<td>F Luminaires with indirect emission</td>
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</table>

The luminaire maintenance factor LMF takes into account the reduction of luminous flux due to the soiling of the luminaire. It signifies the ratio of a luminaire's light output ratios before and after cleaning. The LMF depends on the shape of the luminaire and the related possibility of soiling. The luminaires are classified by their "maintenance factor according to CIE".
These planning examples illustrate why light simulations are useful tools in the planning process. Along with the representation of optimised luminaire arrangement, the visualisations also help communicate the design concept. At the same time, the examples give an account of a historical development – from the first use of virtual luminaires to reflector calculations to the representation of dynamic, coloured lighting concepts.
This selection of projects provides insight into the use of simulations for monuments, religious and administrative buildings and sales rooms.

Chiesa Dives in Misericordia  Brandenburg Gate  Ara Pacis

Scottish Parliament  BMW Mini dealership  Film: Tune the light
Simulation

The lighting design of the Chiesa Dives in Misericordia in 1998 constitutes a milestone in that this is the first time that virtual luminaires from ERCO were used for light simulation. This made it possible to show, check and analyse concept variants at an early planning stage. Approximately 160 virtual luminaires were used in the model of the church. The individual images from the Lightscape program were combined with interactive modules, which were accessible to all designers via the Internet and allowed them to evaluate the various light scenes.

Planning

The lighting concept uses direct, directional light to zone the sanctuary area and to accentuate the main focal points such as pulpit and crucifix. To do this, spotlights were fixed to the steel construction of the skylight. The other component of the concept consists of the uniform illumination of the interior of the arched concrete shell with spotlights and floodlights fitted above the skylights.

Architect:
Richard Meier, New York

Lighting design:
Fisher Marantz Stone, New York

Place:
Rom
The Brandenburg Gate, the symbol of Berlin, has been restored and given a lighting makeover. The lighting designers intensively used light simulations throughout the entire planning process. Trial lighting was not possible as the building was covered throughout the design phase through to the unveiling. Virtual luminaires with their photometric light distribution enabled both qualitative conclusions and quantitative analyses. The results were used to determine the arrangement and alignment of the luminaires. The intensive use of simulations for the competitive tender was a crucial factor in the success of the project.

The columns are accentuated by in-ground lens wallwashers. The wall surfaces of the passages are illuminated by floodlights with an asymmetrical light distribution. In the main, the spotlights for the Quadriga monument on top of the gate were discreetly positioned on adjacent buildings.

Architect: Carl Gotthard Langhans (1732-1808)

Lighting Design: Kardorff Ingenieure, Berlin

Place: Berlin
Simulation

For the simulations of the Ara Pacis, an ancient altar of peace, the designers used the photo texture method. The whole of the temple was photographed and the photos assigned to the individual structural parts. The DIALux program was then used to provide an exceptionally realistic impression. One of the focal points of the simulation was the analysis of the ideal angle of incidence for the relief, to check the formation of shadows resulting from the protruding frieze, and to integrate the luminaires perfectly within the architecture. An external view at night was created using the photo texture of the travertin wall panels. The model was also used for daylight simulations. The building was embedded into the environment in an image processing program. The accessible areas in the building were documented with their illuminance levels and in the form of isolux curves.

Planning

Visitors enter the building through a closed atrium, before the hall with the altar opens up before them, bathed in daylight. Spotlights installed in the niches of the concrete grid ceiling illuminate the reliefs on the temple. The luminaires fitted with daylight conversion filters correspond harmoniously with the light colour of the daylight. The warm light colour of the halogen light, on the other hand, optimally emphasises the colour of the travertine wall panels.

Architect:
Richard Meier, New York

Lighting design:
Fisher Marantz Stone, New York

Place:
Rome
The Scottish Parliament with its asymmetrically vaulted ceilings, its visible roof supporting structure and its seating arrangement for the Parliament has a complex geometry that complicated the lighting design. This situation required the use of light simulations to ensure compliance with the specifications relating to the direction of light and the illuminance for television broadcasts. Due to the fact that the varying distances between luminaire and area to be illuminated resulted in substantial brightness contrasts, the illuminance was calculated on the basis of the faces at the conference table and increased, where necessary, by additional luminaires. The "Autodesk 3ds Max" program enabled the use of virtual luminaires with 3D geometries and photometric data records, which also allowed the designers to check the size of the luminaires in the room.

For the execution phase, a separate application was developed to translate the 3D data on the 900 luminaires of the simulation into 2D drawings and provide the luminous flux, position, alignment and view of each luminaire.
In the plenary chamber, the high illuminance level required for TV broadcasts is achieved using 200 spotlights with Vario-lenses for 150W HIT-CE with 4200K, which also ensure visual comfort for the parliamentarians. The Vario-lenses enable the lighting designer to adjust the beam angles individually to suit the different distances to the illuminated areas.

Architects: EMBT Enric Miralles, Benedetta Tagliabue, Barcelona; RMJM, Edinburgh

Lighting design: Office for Visual Interaction (OVI), New York

Place: Edinburgh

Simulation: Pierre-Félix Breton, Montreal
www.pfbreton.com
Simulation

The simulations for the dealership were used, on the one hand, to review the lighting concept and, on the other, for a realistic presentation of the design to the client. The scope of the simulations included the calculation of illuminance and luminance levels for the vehicles, walls and workspaces to analyse critical luminance contrasts and to evaluate the avoidance of glare. In contrast to the exclusive use of technical drawings with ground plan and section, the visualisations gave those involved in the planning process a better spatial picture of the lighting solution.

Planning

The glare-free general lighting of the showroom is provided by pendant downlights for 150W HIT-CE metal halide lamps. Additional spotlights on suspended light structures emphasise the presentation areas. A row of uplights accentuates the shape of the building and illuminates the cantilevered aluminium roof structure.

Architect: Scaramuzza/Rubelli
Lighting designer: Piero Comparotto, Arkilux, Verona
Place: Brescia
Simulation

The simulation of dynamic, coloured light is extremely complex as seen when moving through a space. In a film, the individual images can differ both in light and perspective. To ensure maximum flexibility in the design, the luminaire groups were calculated separately without setting the final light colour. The video processing program was then used to put together the films of the different luminaire groups and to combine the dynamic colour settings. In this way, the colours could be adjusted without requiring new calculations for the film.

Planning

In the function room, the individual tables are accentuated by narrow-beam spotlights to give them the impression of being islands. Floodlights with variable light colours alter the atmosphere through colour changes, while the projection of gobos creates eye-catching patterns of light.

Simulation:
Aksel Karcher, Berlin
www.akselkarcher.com
In luminaire development, virtual prototyping is used at an early stage in the design process. It is used to analyse aesthetic and technical aspects such as lighting technology, static and thermal calculations. This is done through simulation without the actual luminaire being available. This method accelerates the development process and supports decisions on design alternatives.
To relate the form and aesthetics of the design of a luminaire to existing product photos, a model of the luminaire is simulated in a virtual photo studio. The actual lighting situation of the photo studio is transferred to the software by making a digital image of the photo studio in HDR format. With a mirror ball taking the place of the luminaire to be represented, the photographer takes a series of photos with different exposure times. In the appropriate image processing program, this series is then used to calculate a High Dynamic Range Image (HDRI). HDRI covers a far greater range of luminance contrasts than conventional digital photos. The HDR image is imported as an environment into which the simulation program provides information on beam direction, light colours, relative luminances, types of shadow and reflections, as will exist in an actual photo studio.

Luminaire design: ERCO
Simulation: ERCO; Aksel Karcher, Berlin
The simulation of reflectors provides very precise information on light distribution intensities in a very short time, without having to use expensive tools to produce prototype reflectors. For the reflector simulation, the lamps to be used are initially measured accurately and the individual components of the lamp designated to luminances and other lighting characteristics. Subsequently, the geometry of the light aperture and the lamp position are defined. Starting from a basic reflector form, the designer then changes the contour of the reflector step by step to achieve the required light distribution. After each change of contour, the program calculates the illuminance for a sample area to enable an assessment of the light distribution, and produces a light intensity distribution curve of the virtual luminaire. Programs for reflector simulation are usually based on the (forward) ray tracing method, where the rays of light are emitted from the lamp.
Guide

Glossary

A

Absorption
The ability of substances to neither reflect nor transmit light. Its dimension is the absorption ratio, which is defined as the ratio of absorbed → luminous flux to incident luminous flux.

Accent lighting
Emphasis given to individual areas of a space or to individual objects by specific lighting at a level above that of the ambient lighting.

Accommodation
Adaptation of the → eye to enable objects at different distances to be seen in sharp focus. It is performed by deforming the eye lens.

Adaptation
The ability of the eye to adjust to the → luminances in the field of vision. Performed initially via the dilution or contraction of the pupils, though a far greater scope is achieved by altering the sensitivity of the retina’s receptor cells and by changing between vision with cone cells and vision with rod cells (see also → Eye).

Adapter
A device for connecting a luminaire, especially a → spotlight or → floodlight, both mechanically and electrically to a → track.

Additive colour mixing
Refers to the mixing of colours by the addition of spectral ranges. According to the trichromatic theory, the colours produced by additive colour mixing are the complementary colours of the primary colours (red, green and blue). Mixing the three primary colours in equal amounts produces white light.

Ambient lighting
Uniform lighting of an entire space without giving special consideration to individual visual tasks.

Ambient luminescence
Ambient luminescence provides general lighting for the surrounding area. It ensures that architecture and the objects and people in it are visible. It allows the occupants simply to get their bearings, work and communicate.

Angle of vision
The subtended angle within which an object is perceived; the measurement of the size of the image of an object on the retina.

Anti-dazzle cap
An anti-dazzle attachment for controlling the glare of the direct component of light from the → lamp in the beam direction of the → luminaire. The → beam is restricted in the main direction of the beam and the spill light components are reduced and/or prevented completely.

Anti-dazzle protection
→ Solar protection

Anti-dazzle screen
Anti-dazzle attachment to improve → visual comfort. The cross baffle partially conceals the reflector and the lamp.

Architectural lighting
Term given to lighting concepts and their application, whereby the technical solution is an integral constituent part of the architecture.

B

Backlighting
Type of lighting which is projected from behind the object and casts shadows forward. It can result in a halo of light being visible around the object. In stage lighting, backlighting is used for dramatic lighting effects.

Barn doors
Term given to anti-dazzle plates arranged in a square around the luminaire to reduce the direct glare; typically found on stage lighting projectors.

Beam angle
→ Emission angle

Brilliance
Lighting effect on reflective surfaces or transparent materials. Brilliance is produced by the reflection of the light source or the refraction of light; it requires directed light from point light sources.

C

Candel, cd
Unit of → light intensity; fundamental dimension of lighting engineering. 1 cd is defined as the light intensity emitted by a monochromatic light source with a radiant power of 1/683W at 555nm.

CCG
Abbreviation for conventional → control gear.

Ceiling washlight
Luminaire type which is mounted individually or in rows above eye-level in or on walls. These luminaires illuminate the ceiling area uniformly and without causing glare; they are predominantly designed for → tungsten halogen lamps, → fluorescent lamps or → high-pressure discharge lamps.

Ceramic discharge tubes
Discharge tube of a high-pressure discharge lamp. Ceramic discharge tube technology offers better colour stability and higher → luminous efficacy than quartz technology.

Chromaticity diagram
System for the numerical classification of → colours of light and body colours. The chromaticity diagram is a two-dimensional diagram in which the colour loci of all colours and colour mixes are represented in grades of saturation ranging from the pure colour through to white, which can be numerically expressed by their xy coordinates. Colour mixes are located on a straight line drawn between the colours to be mixed; the → colour of light of → thermal radiators lies on the defined curvature of the Planckian curve.

Colour adaptation
The ability of the eye to adapt to the → colour of light in the surroundings. Results in the perception of relatively natural colour under different colours of light.

Colour compensation
Procedure in lighting engineering for correcting the → colours of light from several luminaires with RGB colour mixing in order to ensure that lighting tasks have a uniform colour impression.

Colour filter
→ Filter

Colour mixing
In lighting engineering, additive colour mixing using red, green and blue can be used to obtain mixed colours. The combination of all three primary colours produces white light. Subtractive colour mixing starts with the primary colours of cyan, yellow and magenta and filters out particular spectral components.

Colour of light
The colour of the light emitted by a → lamp. The colour of light can be expressed by using xy coordinates to specify a colour locus in the → chromaticity diagram. White light colours can also be expressed as a → colour temperature, and can also be broadly categorised as either warm white (ww), neutral white (nw) and daylight white (tw). The same colours of light can have different spectral distributions and a correspondingly different → colour rendition.

Colour rendition
Quality of colours as they occur under a given light source. The degree of colour deviation from a reference light source is given by the colour rendition index Ra.

Colour rendition index
The degree of colour distortion under a given light source in comparison with a reference light source. The optimum colour rendition index is Ra = 100.

Colour saturation
Measure for the intensity of a colour between the pure colour and the white point in the → chromaticity diagram. Together with hue and brightness, this is one of the three fundamental properties of a colour. Colour saturation is usually given as a percentage.

Colour temperature
Describes the → colour of light of a light source. With → thermal radiators, this is virtually the same as the actual temperature of the lamp filament in degrees Kelvin (K). For → discharge lamps, the colour temperature that is most similar is given. This is the temperature at which a → thermal radiator emits light of a comparable colour.
Compact fluorescent lamp
These are → fluorescent lamps with particularly compact dimensions achieved by bending or twisting the discharge tube and/or by combining several short discharge tubes. Compact fluorescent lamps have only one lamp cap.

Compact projector
Spotlight with optical systems for the projection of → lobes and text templates (patterned filters) for use with various lamp types. Depending on the optical system, a distinction is drawn between a condenser projector and an ellipsoid projector.

Condenser projector
→ Compact projector

Cone
→ Eye

Cone vision
→ Photopic vision

Connected load
The connected load is the total sum of the nominal wattages of electric loads.

Connected load of the lighting
The maximum power of the entire lighting installation, regardless of the actual energy consumption.

Constancy
The ability of visual perception to discern features of objects (size, shape, reflectance, colour) despite changes in the environment (distance, position, lighting). Constancy is absolutely vital in order to create a structured image of reality out of the ever-changing patterns of luminance on the retina.

Contrast
The difference in the → luminance or colour of two objects or of one object and its surroundings. The visual task becomes increasingly difficult as the contrast decreases.

Contrast rendition
Criterion for limiting reflected glare. The contrast rendition is expressed by the contrast rendition factor (CRF). It is defined as the ratio between the luminance contrast of a visual task under the given lighting and the luminance contrast under the reference lighting.

Control gear
These devices are necessary for the operation of certain light sources. They primarily refer to current-limiting control gear (chokes) and → starters, i.e. → igniters required to operate → discharge lamps but also to → transformers required to operate → low-voltage halogen lamps. Inductive control gear devices are available either in conventional (CCG) or low-loss versions (LCG). They sometimes require an additional ignitor or starter. Electronic control gear (ECG) work without any additional ignitor and prevent annoying transformer hum or → stroboscopic effects.

Coolbeam
→ Coolbeam reflector

Coolbeam reflector
Dichroic reflector which predominantly reflects visible light, but transmits (glass reflectors) or absorbs (metal reflectors) infrared radiation. Coolbeam reflectors result in a lower thermal load on the illuminated objects. Coolbeam reflectors are also known as multi-mirror reflectors.

Cover glass
The protective layer of a → luminaire through which the light is emitted. Depending on the lighting technology, a luminaire can have one or more such layers. The apparent → luminance of the cover glass is used when evaluating the glare of a luminaire.

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ERCO

Glossary

low-pressure and high-pressure discharge lamps. Low-pressure discharge lamps include conventional fluorescent lamps and compact fluorescent lamps. Their light is produced by exciting the fluorescent substances with radiation. High-pressure discharge lamps include mercury vapour lamps, metal halide lamps and high-pressure sodium vapour lamps. Their light spectrum is due to their unique composition and high operating pressure.

DMX
Abbreviation for Digital Multiplexed. The digital control protocol is mainly used for lighting control with theatrical stage lighting.

Dominant wavelength
Measurement parameter for identifying a mixture of colours by one wavelength. In the chromaticity diagram, the dominant wavelength can be calculated by extrapolating a line from the white point through the given colour locus to meet the spectral colour line. The opposite is the complementary wavelength. The dominant wavelength has various uses including colour classification of LEDs.

Double washlight
A luminaire used in corridors and hallways to provide uniform illumination of the parallel walls and the floor area.

Double-focus downlight
Downlight with elliptical reflector system and Darklight reflector. It provides maximum luminous flux from the smallest ceiling aperture.

Double-focus wallwasher
A luminaire used to provide uniform illumination of walls. The optical system focuses the light into a second focal point and only emits reflected light. This allows the lamp to be completely concealed and only emits reflected light. This produces a more cohesive beam than conventional, mirror-finish reflectors.

Emergency lighting
Term used to describe the lighting of emergency exits and escape routes using emergency lighting luminaires and also to describe the identification of emergency exits using illuminated safety signs or directive luminaires.

Emission angle
The angle between the points of a light intensity distribution curve at which the light intensity drops to 50% of the value measured in the main beam direction. The emission angle determines the light beam diameter.

Ethernet
Data network technology for local networks which permits the exchange of data between all devices connected to a local area network (LAN).

EULUMDAT
European Lumen Data format that describes the light intensity distribution of luminaires.

Exhibition lighting
A type of lighting designed to add visual emphasis to exhibits; it can cover a wide area or be accentuated. In the area of museums and galleries, light protection plays an important role.

Eye
The eye is an optical system containing the cornea and a deformable lens, which project the image of the outside world onto the retina, as well as the iris which broadly regulates the amount of the incident light by adjusting the pupil opening. In the retina, the incoming photostimuli are converted into neuron impulses by receptor cells. The eye has two systems of photoreceptors: the rod cells and the cone cells. The rods are distributed relatively uniformly across the retina; they are highly sensitive to light and enable wide-angle vision under low illuminances (scopic vision). Their visual acuity is low, however, and colours are not perceived. The cones, on the other hand, are predominantly concentrated in the fovea, a small depression in the retina located on the optical axis or visual axis. The cones enable sharp, coloured vision within a limited angle of vision, but require high illuminances (photic vision).

DMX
Abbreviation for Electronic Control Gear.

Elliptical reflector
→ Reflector

Ellipsoid projector
→ Compact projector

Emergency lighting
Term used to describe the lighting of emergency exits and escape routes using emergency lighting luminaires and also to describe the identification of emergency exits using illuminated safety signs or directive luminaires.

Faceted reflector
Reflector with flat facets which produces a more cohesive beam than conventional, mirror-finish reflectors.

Fading
Transition between light scenes. Fading in refers to the starting-up of a light scene, while fading out refers to the ending of a light scene.

Fading time
The duration of the light scene transition is known as the fading time.

Fill light
Type of lighting which discreetly brightens an object, a setting or a time.

Filter
Optical elements with selective transmission. Filters only transmit part of the incident radiation, to produce either coloured light or by filtering out invisible radiation such as ultraviolet or infrared. Filter effects can be achieved by absorption (absorption filter) or reflection (reflection filter). Interference filters are effective reflection filters that work using special vapourised coatings; they are also known as dichroic filters.

Flood
Common term for wide-beam reflectors or reflector lamps.

Fluorescent lamp
A tubular low-pressure discharge lamp containing mercury vapour. The ultraviolet radiation produced by the mercury discharge is converted into visible light by fluorescent substances on the internal surface of the tube. Different colours of light and colour rendition qualities can be obtained by combining different fluorescent substances. The fluorescent lamp usually has heatstrips enabling it to be started with relatively low voltages. Fluorescent lamps require conventional or electronic control gear.

Focal glow
Focal glow creates accents. Light is actively involved in conveying information by visually emphasising areas of significance and diminishing the less important areas.

Fovea
→ Eye

Fresnel lens
Stepped lens where the lens effect is achieved by the concentric arrangement of lens segments. Fresnel lenses are used for stage spotlights and spotlights with adjustable beam angle.

Floodlight
Luminaire with a wide beam angle that can be directed at any point by rotating and tilting; used mainly with track.

Floor washlight
Luminaire type which is fitted either individually or in rows at low level in or on the wall. These luminaires illuminate the floor area uniformly and without creating glare.

Fluorescence
Fluorescence is a process in which substances are excited by means of radiation to produce light; the wavelength of the emitted light is always higher than the wavelength of the incident radiation. One of the primary technical applications of fluorescence is in fluorescent lamps where ultraviolet radiation is converted into visible light.

Gateway
A data exchange protocol that enables communication of different protocols in a network.
Glossary

Guide

General service lamp → Incandescent lamp

Glare
Collective term for the reduction of → visual performance or the impairment of perception due to high → luminances or luminance contrasts in the visual surrounding. A distinction is made between discomfort glare and disability glare: the former concerns an objective reduction in vision and the latter a subjective impairment due to any disparity between the → luminance and information content of the observed area. The glare can be caused by the lamp itself (direct glare) or by → reflection of the lamp (reflected glare).

Global illumination
In three-dimensional computer graphics, a calculation used to describe the simulation of all ways in which light rays may radiate.

Global radiation
The sum of solar radiation and surrounding sky radiation.

Gobo
Common term in spotlight illumination (originally from stage lighting) for a mask or image template (patterned filter) used to create patterns, for a mask or image template (patterned filter) used to create patterns, or for a mask or image template (patterned filter) used to create patterns.

Grazing light
Type of lighting where the light is incident to the surface at a very shallow angle. Used to emphasise surface structure and texture.

High Dynamic Range
Describes a very high contrast relationship in a digital image. Images in HDR format can store a higher luminance contrast than Low Dynamic Range with 255 gradations.

High-pressure discharge lamps
This category includes → mercury vapour lamps, → metal halide lamps and → high-pressure sodium vapour lamps.

High-pressure sodium vapour lamp
High-pressure → discharge lamps containing sodium vapour. Because the sodium vapour is aggressive at high pressures and would destroy glass, the inner discharge tube consists of aluminium-oxide ceramic, enclosed in the external glass envelope. The → colour of light produced is in the warm white range. High-pressure sodium vapour lamps require → ignitors and → control gear.

Honeycomb anti-dazzle screen
Anti-dazzle attachment with honeycomb structure used to restrict the → light beam and reduce → glare.

Hub
Node for connecting network segments or hubs, for example via → Ethernet.

IES
International data format for describing the light intensity distribution of luminaires.

Ignitor
A component in control gear that facilitates the ignition of → discharge lamps by producing voltage peaks.

Interference
Physical phenomenon produced when waves that are out of phase are superimposed; it can result in selective weakening of the intensity of various wavelengths. Interference is used in → filters and → reflectors for selective → transmission or → reflection, respectively.

Interference filter
→ Filter

Iso-luminance contour diagram
Diagram representing luminance distributions, where a single reference plane is shown with contours superimposed of the same luminance.

Isolux diagram
Diagram representing illumination distributions, where a single reference plane is shown with contours superimposed.

Illuminance
The illuminance, measured in the units of lux (lx), is the ratio between the luminous flux incident upon an area and the size of that area.

Indirect lighting
Lighting which is emitted from the luminaires and indirectly reflected onto the working plane via reflective surfaces, e.g. → uplights.

Infrared radiation
Invisible thermal radiation in the wavelength range > 780 nm. Infrared radiation is produced by all light sources, but especially by → thermal radiators, where it constitutes the majority of the emitted radiation.

In-ground luminaire
→ Recessed floor luminaire

Key light
Type of lighting using → accent light to considerably improve the appearance of an object or setting. To avoid harsh contrast, a → fill light is used.

KNX
Abbreviation for Konnex. Standardised digital system for building control, e.g. for lighting, heating and ventilation.

Lambert’s Cosine Law
Law which states that the → illuminance is a function of the distance from the light source. The illuminance is inversely proportional to the square of the distance.

Lamp
Electric light source such as an → incandescent lamp, → discharge lamp or → LEDs. In a → luminaire, the light source produces light which can then be directed to the target objects via → reflectors.

Lamp cap
Component of the → lamp through which the electrical connection to the → lampholder of the → luminaire is made.

Lamp cut-off angle
With → downlights, this is the angle subtended between the horizontal plane and a straight line extended from the edge of the luminaire to the edge of lamp. It is a dimension for the → visual comfort of a luminaire in addition to the → luminaire cut-off angle.

Lamp designation system
Uniform system for naming electric lamps. The abbreviation of a lamp includes information on the method of light generation, the bulb material or gas fillings, the wattage and the type of lampholder.

Lamp life
The functional life of a lamp. The functional life of incandescent lamps is based on the failure of 50% of the lamps. The functional life of discharge lamps and LEDs is calculated at the point when the installation’s luminous flux...
Lens
Optical element used for light guidance. The radius, curvature and surface texture of the lens determine its optical properties. With projector spotlights, lens systems can be used to precisely project images and patterns from gobos. Fresnel lenses can be fitted into spotlights as an accessory in order to spread the light either symmetrically or asymmetrically.

Lens wallwashers
Luminaires with asymmetric light intensity distribution for uniform wall lighting. The light is spread by a lens.

Life
→ Lamp life

Light beam
The term for a beam of light, usually from a rotationally symmetrical reflector. The luminaire's optical system determines whether the gradient of the edge of the beam is abrupt or gradual. With spotlights, the beam can be freely aimed by rotating and tilting the luminaire.

Light beam diameter
The diameter of a → light beam results from the → emission angle and the distance to the → luminaire.

Light fastness
This describes the degree to which a material will be damaged by exposure to light. It primarily applies to changes in the colour of the material (colour fastness), but may also apply to the material itself.

Light guidance
Light guidance by means of → reflectors or → lenses is used in luminaires with defined optical properties to produce luminaires. Light guidance is crucial for visual comfort. The glare of luminaires can be reduced to a permissible level by controlled light guidance.

Light guide system
Optical instrument used to guide light along any route, even around curved paths. The light is channelled along the light guide system, a solid rod or tubular conductor made of transparent material (glass or synthetic fibres, tubes or rods), which function through total internal reflection.

Light intensity
Unit: candela (cd). The light intensity is the luminous flux per solid angle (lm/sr). The spatial distribution of the light intensity of a light source is shown by the light intensity distribution curve.

Light intensity distribution curve
The light intensity distribution curve is obtained by taking a section through the light intensity distribution, which represents the light intensity of a light source for all solid angles. With rotationally symmetrical light sources, the luminous intensity distribution can be shown by a single light intensity distribution curve, whereas two or more curves are required for axially symmetrical light sources. The light intensity distribution curve is generally expressed in the form of a polar coordinate diagram, but with projectors it is often shown in Cartesian coordinates.

Light loss factor
Reciprocal value of the maintenance factor. When designing an installation, this takes the overall lamp failure and general dirt accumulation into consideration.

Light output ratio
The light output ratio is the ratio of emitted → luminous flux to the lamp lumens produced in the luminaire. It is abbreviated as LOR.

Light protection
The limiting of intensity, → ultraviolet radiation and → infrared radiation, required especially in relation to exhibition lighting. Light protection is implemented by choosing suitable → lamps and luminaire types and by → filtering the emitted light.

Light refraction
→ Refraction

Light scene
A lighting situation or a lighting mood with a specific combination of brightness levels and colours. Light scenes can be saved and then recalled either automatically or manually using a → lighting control system.

Light sequence
A series of several consecutive → light scenes. Dynamic scenic lighting is produced by defining the sequential order of light scenes, their duration and the transitions between the scenes using a → lighting control.

Light simulation
A calculation of a lighting situation using software. The quantitative light simulation is used to check the design based on numerical values, while the qualitative simulation is aimed at examining the atmosphere and the aesthetics of the lighting design.

Light source
→ Lamp

Light structure
Arrangement of individual → luminaires connected to form a predominantly linear framework which is usually suspended from the ceiling.

Lighting control
Lighting control enables the lighting of a space to be adjusted to suit different usage requirements and environmental conditions. Each situation is represented by a → light scene, with a specific pattern of switch and dimmer settings for individual circuits. The light scene is stored electronically and can be recalled at the touch of a button.

Local Operating Network
Bus system for communication between installations and devices, for example, for building control systems.
Luminaire
An object containing a lamp and providing artificial illumination. The lamp is held in the lampholder. Reflectors provide light guidance. Luminaires can be permanently installed as surface-mounted, recessed, pendant or free-standing luminaires or track-mounted, which can be variably positioned and aimed.

Luminaire classification
The photometric classification is made using the luminous intensity distribution curve and light output ratio, and also the type of lamp and maximum lamp power; the safety classification is made using the protection mode and protection class.

Luminaire cut-off angle
Angle below which no direct reflection of the lamp is visible within the reflector. With Darklight reflectors the luminaire cut-off angle is identical to the lamp cut-off angle.

Luminaire maintenance factor
A calculation factor determined by the maintenance plan of a lighting installation which considers the drop in luminous flux due to the luminaire design and the reduction in luminaire performance.

Maintenance
Term for the measures taken for the ongoing and effective operation of a lighting installation. It includes replacing lamps, cleaning luminaires and setting the direction of any spotlights. Maintenance is taken into consideration in the design of a lighting system using the parameter light loss factor.

Maintenance factor
Light loss factor.

Mercury vapour lamp
High-pressure discharge lamp containing mercury vapour. In contrast to low-pressure discharge which creates ultraviolet light almost exclusively, mercury vapour emits visible light under high pressure, but with a low red content. The red content can be supplemented and the colour rendition improved by adding other fluorescent substances.

Mesopic vision
Intermediate state between photopic (day) vision using the cone cells and scotopic (night) vision using the rod cells. The levels of colour perception and visual acuity take on corresponding intermediate values. Mesopic vision covers the luminance range from 3 cd/m² to 0.01 cd/m².

Metal halide lamp
High-pressure discharge lamp filled with metal halides. The large number of raw materials available allows metallic vapour mixtures to be created whose discharge generates high luminous efficacy and good colour rendition.

Modelling
The accent lighting of three-dimensional shapes and surface textures using directed light from a point light source. It is generally expressed through the improvement in shadow quality.

Multifunctional lighting
This is a typical lighting requirement in hotels and congress halls hosting seminars, conferences, receptions and entertainment. The multifunctional lighting may be created by using several lighting components which are switched on separately and additionally, often linked to programmable lighting controls.

Multimirror
Coolbeam reflector.

Night vision
Scotopic vision.

Nominal power
The power for which an electric device is designed.

Office lighting
This is specifically oriented about the requirements for VDU workplaces; see VDU lighting. A distinction is drawn between ambient lighting, workplace-oriented ambient lighting and individual workplace lighting.

Perceptual psychology
A branch of the sciences concerned with various aspects of perception, in particular neural response and processing of sensory stimuli.

Permanent Supplementary Artificial Lighting
Additional artificial lighting especially in rooms lit only by windows on one side. PSALI compensates for the fall in illuminance as the distance from the window increases.

Photometer
Instrument used to measure photometric performance. The primary dimension is illuminance, other dimensions are derived from the illuminance. Photometers are adjusted to the spectral sensitivity of the eye. Special measuring equipment called gonio photometers are required for measuring the illuminance distribution of luminaires.
Photon mapping
Algorithm used in light simulation which is primarily employed as an extension of ray tracing based processes.

Photopic vision
Also: day vision. Vision involving → adaptation to luminances of above 3cd/m². Photopic vision is performed by the → cone cells and is therefore concentrated on the area of the → fovea. The → visual acuity is high and colours are perceptible.

Pictogram luminaires
The design of pictogram luminaires usually matches standard directive luminaires and safety signs; pictograms are edge-lit or backlit.

Planckian radiator
Black-body radiator. Ideal → thermal radiator whose radiation properties are described by Planck's Law.

Play of brilliants
Play of brilliants is a decorative lighting component. The brilliant effects can be from lamps or illumination components – from a candle flame and chandeliers to sculptures of light, they contribute to the atmosphere of prestigious and emotive settings.

Point illuminance
In contrast to the average → illuminance, the point illuminance expresses the illuminance at a defined point in space.

Point light source
Term describing compact, virtually point-form sources. The light from point light sources can be optimally directed and focused. Conversely, linear or area light sources produce diffuse light, which becomes more diffuse the more the light disperses.

Projection
Optical image produced by a two-dimensional mask or a → gobo on a surface. Luminaires for projection require an optical imaging system. The focus can be adjusted using a lens system.

Protection class
Indicates the measures taken to prevent contactable metal parts from conducting current in case of a fault occurring.

Protection mode
Protection classification of a → luminaire. The combination of two digits indicates the degree to which the luminaire is protected against the ingress of foreign bodies and water.

PSALI
→ Permanent Supplementary Artificial Lighting

Radiant power
From electrical lamps, this is the product of converted electrical energy. Physical unit: watt. In the wavelength range between 380nm and 780nm, the radiant power (W) is quantified as the → light output (lm).

Radiation intensity
This refers to the radiant power per square metre of area; the maximum value for daylight is approximately 1kW/m².

Radiosity
Light simulation calculation method. With the radiosity method, light rays are emitted from the light source and reflected when they strike a surface.

Point light source
Term describing compact, virtually point-form sources. The light from point light sources can be optimally directed and focused. Conversely, linear or area light sources produce diffuse light, which becomes more diffuse the more the light disperses.

Ray tracing
Light simulation calculation method. The ray tracing method is based on rays of light that are emitted from an imaginary eye to the model and the light sources.

Recessed floor luminaire
A luminaire which is flush-mounted in the floor or ground and has a high → protection mode. These luminaires are used to mark out routes and pathways and also to dramatically illuminate objects and architectural details.

Recessed luminaires
→ Downlight

Reflection
The ability of surfaces to reflect light. The percentage reflection is known as the reflectance, defined as the ratio of reflected to incident → luminous flux. Reflection can be directed or diffuse.

Reflecting surface
A surface that is capable of re-directing light from a source. Reflecting surfaces are classified in terms of their reflectance, which is quantified as the percentage of light reflected from the source.

Reflective surface
A surface that is capable of re-directing light from a source. Reflective surfaces are classified in terms of their reflectance, which is quantified as the percentage of light reflected from the source.

Refractance plan of a lighting system
Calculation value for the maintenance factor of a lighting system.

Restoration
The restoration of a lighting system to its original condition, typically after a period of disuse or maintenance.

RGB
Abbreviation for Red Green Blue. The RGB colour mixing used in lighting technology is based on additive colour synthesis to produce light of different colours.

Refractive index
A dimensionless quantity that describes the ability of a medium to bend or refract light. The higher the refractive index, the more the light is bent as it passes through the medium.

Refractive power
Given by the refractive index of a medium. The higher the refractive power, the more the light is bent as it passes through the medium.

Refractive system
A system that is capable of re-directing light from a source. Refractive systems are classified in terms of their refractive power, which is quantified as the ratio of refracted to incident → luminous flux. Refractive systems can be directed or diffuse.

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Resistant surface
A surface that is capable of re-directing light from a source. Resistant surfaces are classified in terms of their resistance to light, which is quantified as the percentage of light reflected from the source.

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Refractive power
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Refractive system
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Recovery of light
The recovery of light from a source, typically after a period of disuse or maintenance.

Reflectance
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Refractive index
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Guide

Glossary

lighting) and tungsten halogen lamps (accent lighting). Such retail lighting can often be used to convey a company's corporate identity.

Solar architecture
Architecture designed to allow solar energy and daylight to be utilised as energy and light, respectively.

Solar protection
Technical measures which use absorption, reflection and refraction to control direct sunlight in order to improve the visual comfort (glare protection) and reduce the thermal load in the room.

Solar simulator
Daylight simulator

Spectrum
Distribution of radiation intensity of a light source over a specific range of wavelengths. Both colour of light and colour rendition are a result of the spectrum. The basic types of spectrum are distinguished depending on how the light is produced: the continuous spectrum (daylight and thermal radiators), the linear spectrum (low-pressure discharge) and band spectrum (high-pressure discharge).

Spherolit reflector
Light-redirecting system based on reflective segments with spherical shapes. The light intensity distribution is determined by the reflectance, the reflector contour, the number of spherical segments and the segment radii.

Spill light
Unwanted light emitted outside the main beam. Spill light can cause glare, and outdoors, for example, it is often a source of light pollution.

Spot
Common term for narrow-beam reflectors or reflector lamps.

Spotlight
Luminaire in which the predominant direction of light distribution can be aimed at any desired point by rotating and tilting; used mainly with track.

Starter
Ignitor for fluorescent lamps.

Stroboscopic effect
This is a flickering effect which results in the apparent change in the speed of moving objects. This can even go so far as to make objects appear to be stationary or move in the opposite direction. It is caused by light pulsating at or close to mains frequency. Stroboscopic effects can occur when lighting is provided by discharge lamps. It can be remedied by phase-shifted operation (lead-lag circuit, connecting to a three-phase power network) or by high-frequency electronic control gear.

Sunlight
Daylight

Thermal radiator
A radiation source from which light is emitted by heating a material, generally tungsten, as the filament material in an incandescent lamp.

Thermoluminescence
Luminescence

Tungsten halogen lamp
Compact incandescent lamp filled with halogen to prevent the deposit of vapourised filament material onto the inner glass wall. Tungsten halogen lamps have a higher luminous efficacy and longer functional life than general service lamps.

Twilight vision
Mesopic vision

Ultraviolet radiation
Invisible radiation beyond shortwave light (wavelength 380 nm). Light sources used in architecture usually only emit a limited amount of ultraviolet radiation. Ultraviolet radiation can have detrimental effects, particularly causing colours to fade and materials to become brittle. Ultraviolet filters absorb this radiation.

Uplight
Pendant luminaires, wall luminaires, floor luminaires or free-standing luminaires that emit their light upwards.

Utilisation factor
This factor describes the influence of spatial geometry and the reflectance of its peripheral surfaces on the residual luminous flux arriving on the defined working plane.

Utilisation factor method
Method for calculating the average illuminance in a room using the light output ratio, the utilisation factor and the luminous flux of the lamp.

Varychrome
Attribute describing luminaires that can generate light of any colour, for example, using RGB colour mixing.

VDU lighting
Lighting in administrative buildings which is heavily regulated by guidelines and regulations. It is characterised by requirements for the illuminance level, light distribution and glare limitation, specifically for preventing reflections on monitor screens, worktops and keyboards.

Visual acuity
This term is used to describe the ability of the eye to perceive detail. It is measured in Visus, defined as the inverse value of the size of the smallest perceptible detail of a specified visual task in minutes of a degree.

Visual comfort
Visual comfort expresses the lighting quality with regard to parameters such as illuminance, elimination of glare and colour rendition.

Visual performance
This term is used to describe the ability of the eye to perceive the visual properties of the object to be viewed. The difficulty of a visual task increases as the...
colour contrast or luminance contrast decreases, and also as the size of detail decreases.

Voltage
Physical dimension. Causes charge carriers to be set in motion and electrical current to flow in an electrical conductor.

W

Wallwashers
Luminaire with special reflector system or reflector lens system for uniform lighting of walls; it is essential that the wallwashers are spaced equally and are parallel to the wall.

Warm white, ww
→ Colour of light

Washlight
Luminaire with a combination of darklight reflector and ellipsoid reflector which achieves a high level of visual comfort combined with even wall lighting; the prerequisite for this is the regular arrangement of wallwashers parallel to the wall.

Watt
Physical unit of power. It is the product of → voltage and current.

Wide flood
Common term for very wide-beam reflectors or → reflector lamps.

Workplace lighting
In general, this refers to the lighting of workplaces; specifically, it refers to the additional lighting of workplaces which is designed to suit the actual visual task and is additional to the ambient lighting.